This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

ELECTRICITY:

THEORY SOURCES & APPLICATIONS

JOHN. T. SPRAGUE.

University of Wisconsin
LIBRARY.
No. 22571
TN
.Sp7

ELECTRICITY:

ITS THEORY, SOURCES, AND APPLICATIONS.

ELECTRICITY:

ITS THEORY, SOURCES, AND APPLICATIONS.

BY

JOHN T. SPRAGUE,

MEMBER OF THE SOCIETY OF TELEGRAPH ENGINEERS AND ELECTRICIANS.

SECOND EDITION

(Greatly Enlarged).

LONDON:
E. & F. N. SPON, 16, CHARING CROSS.
NEW YORK: 35, MURRAY STREET.
1884.

25571

6968806

TN
.Sp7

PREFACE.

THE fact that the first edition of 2000 copies of this work has been readily purchased, together with letters received from electricians and students all over the world, may be taken to justify the author in believing that, in departing from the nearly universal system of electrical text-books, he has met a widely felt want.

There are two electricities known to the scientific world: the electricity which exists in nature; and the electricity which, created by mathematicians, exists chiefly upon the blackboards of the professor's class-room. It is the first of these electricities which this work endeavours to elucidate. The artificial electricity serves a very useful purpose in calculating the effects which we may look for when using electricity. But that it does not satisfy earnest thinkers is manifest from the fact that recent text-books are gradually adopting and teaching doctrines which were accounted utter heresies when this book first appeared.

As stated in the preface to the first edition, the work was based upon papers which had appeared in the 'English Mechanic' and the 'Telegraphic Journal,' and much of the new matter in this edition has in like manner appeared in the pages of the 'Electrician.'

A few words as to the object of the Author may prevent some misconception. The work is not intended to enable the reader to "cram" for an examination, but to lead him to *think for himself;* not so much to give specific instructions as to any special case, as to assist in forming a clear conception of those general principles which include all cases; and it is hoped that the great number of questions which have been addressed to

30 N 91

the Author will have enabled him to understand, and in considerable degree to meet the desires of the class of readers for whom the work is intended.

As stated in the first preface, "the object has been to review the leading and essential facts, and to so systematize them as to form of them a *catalogue raisonné*, in which all information obtained elsewhere may be readily inserted, and be as readily available when required. Many mere facts found in all other books on electricity may here be omitted, or only slightly glanced at; but on the other hand, *principles* are dwelt upon, and the instruments necessary for their study fully explained, so that those who may have some mechanical aptitude may construct them for themselves, the very best possible way of understanding them."

It has been the aim of the Author to keep up with the great and rapid progress of electrical applications, so that the work is very greatly enlarged and several additional branches of the subject taken up. The rapid advances made, and the fact that the work has been eighteen months in passing through the press, may account for some peculiarities in the arrangement and treatment of some parts of the subject.

In these days of claims and counterclaims as to priority of ideas, it may be as well to remark that the history of electric discovery and progress does not enter within the scope of this work, but that, where occasion calls for reference to such subjects, it has been the desire of the Author to give honour where honour is due upon purely scientific considerations.

117, GREEN LANE, BIRMINGHAM,
April, 1884.

CONTENTS.

CHAPTER I.

INTRODUCTORY.

Matter. Atoms. Ether. Valency and atomicity. Molecular types. Chemical notations, equivalent and atomic. Force and Energy as related to matter. Electricity not convertible into work. The two constituents of electricity, a molecular function and energy .. .. .. Pages 1–13

CHAPTER II.

STATIC OR FRICTIONAL ELECTRICITY.

Primary condition of development. Electrics and conductors. The Electrophorus. Electroscopes. Primary experiments. Clerk Maxwell and Dr. Lodge on Charge, Potential, and Repulsion. Repulsion non-existent. The Fluid theories. Molecular polarization. How it produces electricity. Meaning of connection to earth. Earth not a reservoir. Surrounding surfaces and induction.—35. Frictional machines. Induction machines. The Voss and Holz machines. Electrometers. Dry piles.—51. The Leyden jar. Condensers. Charge and induction. Quantity. Density. Attraction and repulsion. Tension. Potential, definitions of.—62. Distribution. Actions of points. Surface density. Induced charges. Condensation. Bound electricity, meaning of. Inclosed spheres. Inductive and conductive circuits. Capacity. — 76. Relations of Static and Dynamic electricity. Dielectrics, properties of. Retardation. Specific inductive capacity, table of. Paraffin, uses of.—83. Discharge. Properties of the electric spark. Velocity of electricity; its dual nature. Polar actions and formation of the electric field of force 14-91

CHAPTER III.

MAGNETISM.

Magnet and filings. Curve of force. Magnetic curves. Molecular constitution of magnets. Relation to electricity. Ampère's theory. Molecular theory. The magnetic field. Reason of attraction and repulsion. Bjerknes and Stroh: their mechanical illustrations. Magnetic force, laws of.—104. Magnetizing. Steel for magnets; forms of. Influence of heat.—107. Terrestrial magnetism. The earth a magnet. Position of its poles. Variation. Horizontal intensity. Magnetic field, strength, moment. Magnetic intensity and capacity.—112. Auroras. Magnetic storms. Diamagnetism. Relation of magnetism to absorbed energy. Magnets have no proper work power, or force 92–114

CHAPTER IV.

GALVANIC BATTERIES.

Zinc in acid. Zinc and copper. Heat or energy developed. Molecular polarization set up. Definition of poles and plates. General principles. Relations of energy to matter and to molecular constitution. Sources of quantity and electromotive force. Amalgamation. Zinc. Sulphuric acid. Size of cells. E M F and size. Resistance. Current, constancy. Density of current.—131. Copper and zinc cells. Platinized silver. Various forms of construction. Porous jars. Electric endosmose.—137. Daniell's cell; various forms of: E M F of. Nitric acid, table of strengths. Aqua regia. Bichromate of potash. Voisin's red salt. Iron in batteries. Platinum.—152. Carbon: artificial: connection to. Circulation of liquids. Various constructions. Bichromate battery. Manganese. Leclanché. Alkaline cells. Fitting up batteries. Commutators.—168. Work and constancy of cells. Cost of working. Proper use of different batteries.—172. Secondary batteries, charge and discharge of. Planté. Faure. Formation. Construction. Loss of gases. Faure's battery. Other makes. Management, and work capacity of .. Pages 115–189

CHAPTER V.

MEASUREMENT.

Galvanometers: needles for. Astatic needles. Laws of angles. Horizontal magnetic intensity. Tangent galvanometer. Sine. Curves of action and of graduation. Sprague's Universal. Differential. Thomson's Reflector. Voltameters. Ratio of gases to current. Calorimeters. Heating of wires. Coulomb-meters. Electric meters.—223. Principles of measurement. Natural units. The B. A. system. Absolute units. Force and Energy. Gravitation. The C. G. S. system. Electric units, dimensions of. The practical units. Volt. Ohm, &c., general table of.—237. Resistance measures, construction of. Wheatstone Bridge. Potential, distribution of. Resistances and bridge combined 190–255

CHAPTER VI.

CURRENT.

Quantity and intensity. Ohm's laws. Analogy of electric and water current. What resistance really is. Electromotive force. Mechanico-motive force. Potential energy. Laws of falling bodies. Relations of Force, Energy, and Potential. Potential considered as representing square root of energy. Laws of Current. Why resistance so called is equal for all currents. Hydraulic analogy of current. Chemical value of the ampère 256–271

CHAPTER VII.

CONDUCTIVITY AND RESISTANCE.

Specific conductivity. Alloys. Heat and conductivity. Resistance, definition of. Resistance as a velocity. Work as resistance. Counter or −E M F. Inductive resistance. Energy absorbed in magnetizing. Derived circuits. Shunts. Internal resistance of cells, measurement of. —283. Conductivity of Metals, &c.: Table of. Temperature correction. Dimensions of wires. Wire gauges, various. Formulæ and constants of wires. Purity of copper.—294. Table of wires. Resistance of liquids. Earth circuit. Heating of wires. Dissipation of heat by conduction, convection, and radiation. Safe current in wires. Cost of conduction. Pages 272–307

CHAPTER VIII.

ELECTROMOTIVE FORCE.

Measurement of E M F: apparatus for. Experimental processes. Relations of energy and matter. Mechanical equivalent of heat. Intrinsic energy. Combustion. Salts.—319. Table of properties of the elements. Energy of chemical processes. How energy becomes E M F. The equivolt.—325. Table of correlation of units, &c. Contact and chemical theories. General law of energy. Electric circuit, phenomena of. Positive metal sets up E M F. Action at negative plate.—336. Table of E M F of batteries. Details of energy in electric actions. E M F and chemical affinity. Work and the square of current. Energy expended in circuit. Potential considered as energy 308–355

CHAPTER IX.

ELECTROLYSIS.

Terms used. Generating and decomposing cells. Diagram of full circuit. Laws. Valency. Theories of Berzelius and Faraday, opposed and united. Gas volume. Electric equivalent. Counter E M F of electrolysis. Formula of work. Decomposition cell a condenser. Transmission in liquids. Secondary actions. Action at electrodes. General law of minimum energy. Mixed electrolytes. Water not an electrolyte. Typical reactions. No transfer of ions. The work of electrolysis .. 356–385

CHAPTER X.

ELECTRO-METALLURGY.

Electrotyping and Electro-plating. Preparation of objects. Cleanliness. Cleaning processes for different metals. Old work. Moulds. Plaster of paris. Elastic moulds. Insects and flowers. Conducting surfaces. Stopping off. Smee's laws. Strength of solutions. E M F and resistance required. Density of current. Tension. Rate of deposit. Effects of position. Circulation. Size and distance. Apparatus. Principles of solutions.—414. Depositing copper. Bronzing. Rate of work. Cyanide of potassium. Silver depositing. Spoilt solutions. Gilding. Coloured gold. Nickeling. Iron and platinum. Alloys. Brass and bronze deposits 386–440

CHAPTER XI.

TERRESTRIAL ELECTRICITY.

Earth currents; causes and laws. Magnetic storms. Supposed static charge of the earth. Theories of earth magnetism. Cosmical electricity. Maxwell's theory of light. Atmospheric electricity. Supposed causes. Potential energy of vapour. Earthquakes, volcanoes, and cyclones. —449. Thunder-storms. Ball lightning. Duration and brightness of lightning. Lightning conductors: laws of.—455. Earth connections. Faraday's comparison of Static and Dynamic electricity explained. Quantity and Potential both included in the usual expressions Pages 441–460

CHAPTER XII.

ELECTRO-MAGNETISM.

Electric actions in conductors. Reactions of currents on magnets. Static and magnetic charges are potential energy stored. Right and left handed helices. Theory of magnetic field. Induced currents in conductor crossing the field.—473. Dynamo-electric machines. History of the earlier forms. Evolution and development. Principles of all dynamo machines. All matter exists under a balance of varying forces. How magnets develop currents.—490. Action of the field magnets. The Gramme machine, the Siemens machine, the Bürgin, and others. Laws of proportion. Shunt, series, and compound machines. Laws of E M F developed. Characteristic curves. Efficiency of machines. — 514. Electric motors: various types. Relative efficiency of motors. Cost of working.—519. Energy of fuel. Gas as fuel. Cost of mechanical energy. Cost of electric energy. Transmission of energy.—523. Electro-magnets, laws of. Magnetic capacity of iron and steel.—530. Induction coils, laws and construction of. Mercury breaks. Dimensions of noted coils. Medical coils. Management of wires 461–547

CHAPTER XIII.

ELECTRIC LIGHTING.

Light a motion and a perception. Sound; absorbed notes. The spectrum; dark lines. Draper's experiment. Degrees of Temperature, Table of. Ratios of light to energy. Photometry: standard of light: chemical measures. Absorption. Distribution of light.—559. Light not produced from electricity; energy its source in all lights alike. The voltaic arc: its temperature. Colours by arc light. Penetrating power: resistance and E M F. Products of the arc. Uses of the arc light. Heat rays.—556. Arc lamps: differential principle. Werdermann lamp. Jablochkoff and other "candles." Preparation of carbons.—570. Incandescent lighting. Atomic heat and volume: radiation capacity. Swan's first lamps. —575. Form and size of carbon wires. Efficiency of lamps. Advantages of incandescent system. Law of light ratio to current and work. Cost of the light 548–582

CHAPTER XIV.

MISCELLANEOUS.

Telegraphy: duplex and quadruplex. Automatic transmission. Electric organ. The Motograph. Electric Bells: construction and system. Switches. Telephony. The Phonautograph. String Telephone. Phonograph. The Telephone: order of invention. Current required. Construction. Action of the Telephone. Edison's transmitter and receiver. Use of induction coils. Varley's and Dolbear's condenser, and other forms. Induction and its remedy. The Microphone. Various theories of. Air film a conductor. Relation of resistance to current and pressure. Principles of construction. Distance of transmission. Telephone system and circuit. Radiophony. Selenium and its properties. Hughes' induction balance. Microtasimeter. New source of electricity. Wimshurst machine. Thermo-electricity. Clamonds and Noe's piles. Conservation of electricity .. .. Pages 583–623

CHAPTER XV.

DICTIONARY OF TERMS.

Short definitions and explanations 624–638

INDEX 639

ELECTRICITY.

CHAPTER I.

INTRODUCTORY.

1. It is a common remark, that it is desirable to know everything about one subject, and a little of every other subject. In science this is certainly requisite, for it is impossible to study any one branch thoroughly without aid rendered by the knowledge of several other branches. Before we can understand electricity and its various applications, we require to have some knowledge of the fundamental principles of mechanics, the laws of motion, energy, force, and heat, and above all we need some considerable acquaintance with the general principles of chemistry.

C

This is not so evident when electricity is studied, as is too often the case, rather as a department of mathematics than as one of the prime agencies of nature. But in this work the latter is the point of view adopted, and therefore, as chemistry has gone through great changes of late years, and its terms and doctrines are differently treated by different writers, I think it better not to refer the reader altogether to works treating of this branch of knowledge, but to give here the necessary general outline of the facts, principles, and terms which will be employed, to serve as it were as an outline chart, by which we may afterwards travel intelligently through the land we desire to explore.

2. **Matter.**—Of the essence or nature of matter itself we know absolutely nothing, and never shall know anything; but of its properties, whether they be inherent in its own essence or due to the action of forces connected with it, we know a good deal.

Matter, as known to us, consists of certain forms which we call elements, because they are the simplest substances we have yet attained to. These may, for all we know, be composed of varying mixtures of yet simpler forms of matter; but true science, as distinguished from metaphysics, refuses to admit the "*may be*," but rests on what is *proved*. Therefore, in science, matter means the elements and their compounds.

3. **Elements.**—Of these at present sixty-five are known, besides several recently discovered or supposed to have been isolated. They exist as gases, such as hydrogen and oxygen; as liquids, like bromine and mercury; and as solids, such as carbon and the long list of metals; but these physical states are not essential to their nature, they depend only on their existing relations to force, as heat and pressure; and as we can, by altering the conditions of force, cause most of them to pass from one state to the others, so there is no reason to doubt that every gas can assume the solid form, and every solid become a gas, under sufficiently altered conditions of force.

4. **Atoms.**—There is abundant evidence that these elements exist in the form of ultimate particles called atoms, possessing definite dimensions and weight. Though these atoms are practically infinitely small, and beyond our powers of measurement or even conception, yet their existence is not a mere hypothesis, but a logical deduction from well-proved facts. All the actions of matter prove their existence, and the whole framework of modern chemistry, and, indeed, of all the natural sciences, is based on the atom.

There have been many discussions as to the actual existence of atoms, which have been really battles about words. "Atom" means, in fact, incapable of division, and it requires no elaborate mathematical analysis to show that any particle having dimensions and weight, however small, must be theoretically capable of being divided: but we need not encumber ourselves with any hypothesis as to the atom being infinitely hard and so on, as subtle reasoners about things beyond our knowledge continually do; all we need is to consider the atom as the ultimate particle of each form of matter, and that if divided, it would no longer remain that form of matter.

The atom has several relations to force: (1) to gravity, which depends on its mass simply, without reference to its nature; (2) to heat, which for each physical form of matter is the same for all atoms; (3) chemical affinity, which varies between every different class of atoms.

5. **Ether.**—Besides the ordinary known matter there appears to be something pervading all space, though so *thin* or attenuated as scarcely to come within the common idea of matter as something tangible. That it exists astronomy affords us actual evidence, but what it really is we have no means of ascertaining, because it is impossible to lay hold of and analyze it; but the more we learn of the actions which take place in our own and

the other suns, the more probable it becomes that it is ordinary matter in an ultra gaseous condition, but whether retaining the state of ordinary elements, or whether resolved into a more simple form, or even into a non-atomic state, we do not know, nor are we ever likely to learn except by deduction from its actions. The interesting researches of Dr. Crookes into those extreme vacua now obtainable by means of the mercury pump, (and which are readily carried to the one millionth of an atmosphere) strongly suggest to the scientific imagination that this so-called "fourth state of matter" may actually be the interstellar ether. Be this as it may, all systems of physical philosophy alike require this so-called "ether," for so far as the probabilities of several hypotheses are concerned, there is no difference between this one ethereal form of matter transmitting the impulses of the forces, and a luminiferous agent issuing from the sun, or an electrical fluid pervading space and matter, except that the first—the modern theory—is by far the most simple and most accordant with the facts needing explanation.

This hypothetical ether is being gradually made to fulfil more and more of the functions for which the older philosophers invented separate "fluids," and in this there lies a new danger for real science. We know absolutely nothing about the ether, and these applications of it are little more than guesses: but when a word is invented to cover a difficulty, people easily come to believe that this word actually explains the matter.

6. ATOMICITY OR VALENCY OF ATOMS.—Within the last few years chemistry has undergone a complete revolution, and one of the leading features of the new system is the idea of molecular types, these being due to the atoms having different exchangeable values. One of the oldest ideas of the atom was that matter had no real existence, and that atoms were simply centres of force. The modern idea is, that though the atom is a material body, it acts as a centre of force, and that the atoms of different elements differ by possessing one, two, or more such centres, or foci of influence. Hence the elements are classified as monads, monatomic or univalent, having only one attraction, such as hydrogen, chlorine, &c.; dyads, diatomic or bivalent, having two attractions, as sulphur, or oxygen; triads, triatomic or tervalent, with three attractions, as nitrogen; tetrads, tetratomic or quadrivalent, having four attractions, as carbon, and so on.

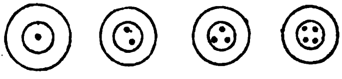
The words atomicity and valency are frequently used as synonymous, but there is a tendency to attach the first term more to the theoretical explanation of the nature of the atom, while valency expresses the fact that atoms of the weights now accepted, do, in combination or substitution, replace 1, 2, 3, or 4 atoms of hydrogen. This involves no theory, and whenever I use the word valency it must be understood as expressing this fact, not as necessitating the explanation of which an outline follows.

7. It is conceived that the atoms of which matter is built up are not in absolute contact, but are separated by spaces (containing ether) in which they move freely under the several forces to which they are exposed, these motions replacing in modern theory the atmospheres of forces or fluids which used to be believed in. The atoms are held together by the attraction or force which we call affinity, exerted across these intervening spaces.

In any act of combination or decomposition, nothing less than one atom of any substance concerned can take part or undergo a change of its relation to other substances, but these relations are governed by the number of attractions proper to itself. Thus an atom of hydrogen (1) can only combine with one atom of chlorine (1) to constitute hydrochloric acid; two atoms of hydrogen (1) unite with one of oxygen (2) to form water; three atoms of hydrogen with one of nitrogen (3) form ammonia, and four with one of carbon (4) make marsh gas, these being four of the typical forms to which chemical combinations are referred, not merely for convenience, but because they are all bodies actually existing and playing important parts in the chemistry of nature, and also because they are forms which would result from the several atomicities, if these really exist.

As to the actual shapes of the atoms we know nothing, but to enable readers more clearly to realize the theory set before them, I employ diagrams in which the several atoms are represented by circles containing dots to mark their atomicities, and surrounded by another circle to mark the space which separates them from each other and in which they move, but it must be understood that these diagrams are only aids to the imagination; they represent ideas, but by no means must be taken for actual pictures of the things they may aid us to conceive. We may therefore picture the various classes of atoms as in Fig. 1.

FIG. 1.



8. THE MOLECULE.—Formerly the words atom and molecule were treated as almost synonymous, but the rapid growth of modern chemistry has required a more exact definition of ideas, though even yet, as to compounds, the word molecule is not

unfrequently used where atom or radical would be more correct. The strict meaning of the word now is the smallest quantity of a substance which is capable of separate existence as a free body. With this meaning the word is equally fitted for use in chemistry and in general physics.

It is therefore a body in which all the attractions or valencies are satisfied, leaving the combined atoms to act as a whole from one centre, so far as such forces as gravitation, cohesion, heat, &c., are concerned. A body whose atomic attractions are not thus satisfied, though it be complete in one chemical sense, and has a real existence, yet cannot exist by itself, and therefore is not a molecule but a compound atom or radical, because indivisible without change of nature; to become a molecule it must unite with another body or bodies sufficient to satisfy its attractions.

This applies equally to elementary and compound bodies, and therefore every molecule must consist of at least two atoms—distinct, yet united—and acting as a whole on surrounding bodies. Hence a piece of copper wire is not built up of atoms, as in Fig. 2, but the atoms are coupled together first, as molecules, as in Fig. 3.

It is evident that as regards simple elements, two atoms, whatever their atomicity, can form a molecule by satisfying each other, and this is the usual form of elementary molecule; but there are some of which the molecule may probably contain several atoms, and others, such as carbon and phosphorus, which exist in several conditions, or allotropic states, the cause of which may be, that the molecules in these different states contain different numbers of atoms, and different energies.

FIG. 2.

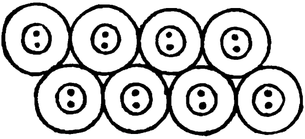
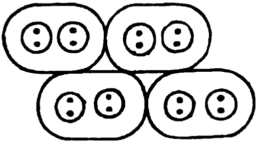


FIG. 3.



9. **MOLECULAR TYPES.**—When different elements enter into combination, the number of atoms forming the molecule will depend on the relative valencies of the several atoms, and hence we arrive at certain typical forms or molecular skeletons, to which all compound bodies are related. A univalent atom can only join a single univalent atom, and this furnishes the first type, Fig. 4. Here the two atoms, 1 and 2, in molecule A, may be both hydrogen H′ H′, or both chlorine, Cl′ Cl′ forming the

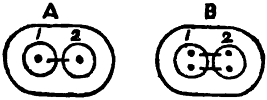
free molecule of hydrogen or chlorine; if 1 is hydrogen and 2 chlorine we have H′ Cl′, the molecule of free hydrochloric acid; and if we substitute sodium for the hydrogen in this, we have Na′ Cl′ the molecule of common salt, and if we now substitute iodine for the chlorine we have Na′ I′ iodide of sodium. Fig. 4 A, in fact, shows a molecular frame, which we may fill up at pleasure with univalent substances without destroying the molecular constitution, and when submitted to the action of an electric current, the body, be it what it may, which occupies the position of atom 1, will always appear at one pole, and atom 2 at the other pole. Thus, if we consider these figures to represent the ordinary chemical formulæ, 1 would be the basic radical or ion and 2 would be the acid radical, and in electrolysis the substance would arrange itself as

$$\begin{array}{ccccc}
 & \longleftarrow & & \longleftarrow & \\
-\text{ pole} & \left\{\begin{array}{l}\text{cathode}\\ \text{plate } -\end{array}\right. & \left\{\begin{array}{cc}1 & 2\\ + & -\\ \text{Cu} & \text{SO}_4\end{array}\right\} & \left.\begin{array}{l}\text{anode}\\ +\text{ plate}\end{array}\right\} & \text{pole } + \\
\downarrow & & & & \uparrow \\
\text{Zinc } + & & \underset{\longrightarrow}{\text{Daniell cell}} & & -\text{ Copper.}
\end{array}$$

The molecular equilibrium will not even be destroyed if we substitute a compound atom or radical for either or both of these atoms; thus, returning to the sodium iodide, the iodine may be replaced by cyanogen Cy′ (which being C^{IV} N''' has one attraction unsatisfied) producing sodium cyanide Na′ Cy′, and then finally the sodium may be exchanged for the monatomic radical of alcohol, ethyl C_2H_5 to form cyanide of ethyl. I have gone somewhat fully into this type, in order to give the general principle applicable to all—viz. that any typical atom in any molecule may be replaced by another atom of similar valency, without altering the arrangement of the molecule, and in so doing its chemical properties will only be gradually affected, according to the properties of the substituted atoms, without changing its relations to electrical force.

Molecule, B, in Fig. 4, is intended to show that the same type includes bodies of higher valency, where only two atoms of equal valency, each satisfying the other, are contained in the molecule; so that this type includes the molecules of the elements, and of many radicals in the free form, though A, Fig. 4, is that which is called the hydrochloric acid type.

Fig. 4.

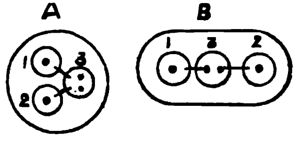


The next is the WATER TYPE $\left.\begin{matrix}H\\H\end{matrix}\right\}O$ or H_2O, in which one bivalent atom unites with two univalent atoms. Fig. 5.

Here, as in the first and in all other molecular forms, each atom is capable of being exchanged for any other of equal value: thus, the hydrogen atom 1 may be replaced by potassium, and we have $\left.\begin{matrix}K'\\H'\end{matrix}\right\}O''$ hydrate of potash; again, 2 may be similarly replaced, giving $\left.\begin{matrix}K'\\K'\end{matrix}\right\}O''$ or K_2O, potassium oxide; or instead of the hydrogen, the oxygen atom 3 may be exchanged for another bivalent atom, as sulphur giving $\left.\begin{matrix}H'\\H'\end{matrix}\right\}S''$ or H_2S, sulphuretted hydrogen.

Two ideal forms of this molecule are given, because neither will convey the whole truth, for we may conceive that both the hydrogen atoms are equally held to the oxygen in water, which is the form A, or one of them may be held more strongly than the other. There is good reason to suppose that the latter is the case in ordinary circumstances, and that atom 1 of the H is more closely united than 2 to the O; that HO first form a univalent radical known as hydroxyl, to which the second atom of hydrogen is united. A strong support to this idea is found in what are called isomeric bodies, containing exactly the same elements in the same proportions, yet having somewhat different properties. It is evident that in Fig. 5 B there would be a difference according as atom 1 or 2 was replaced by another element. Still, Fig. 5 A is also true, for both 1 and 2 may be removed together and replaced by a single bivalent atom, in which case, however, we should consider the type was changed to that of Fig. 4 B: under the influence of an electric current, there is good reason to suppose that the molecule takes the form A, the atoms 1 and 2 passing to one pole, and atom 3 to the other pole. It is not necessary to go further into the subject of the types of molecular construction until the action of the electric current in electrolysis has to be considered; at present the main thing is to obtain a clear conception of molecules as the ultimate particles of matter in all its ordinary forms; as the bricks, so to speak, with which the substances known to us are constructed on regular systems of architecture, and to comprehend that they have a capacity of separating into at least two parts, which are held together by a mutual attraction.

FIG. 5.



10. It will be seen that there are thus two classes of molecules.

(1) *Molecules which are also atoms*, being indivisible without change, as water, and all salts and acids. These molecules are held together by high affinities, varying in each case, and require considerable force for their decomposition.

(2) *Molecules formed of two similar atoms* or radicals, held together by their unsatisfied attractive foci, but by a feeble affinity; these are capable of division into two similar parts, and that by a small expenditure of force. This is the state in which exist, as free bodies, the elements and those compound radicals (such as cyanogen) which have many of the properties of elements, though known to be compounds.

We may conceive the molecule as representing on the infinitely small scale the solar system itself, which is built up of several systems or parts, each complete in itself, yet all linked to each other and forming a balanced whole: thus Mercury and Venus stand as single atoms, the earth, Jupiter, and Saturn, with their moons, resemble the compound atoms or radicals composed of several distinct atoms so united as to play the part of a single atom in the mighty molecule, which again forms but an infinitesimal part of the complete universe, held within it by forces acting across infinite space, as our molecules are united into visible substances by the forces of cohesion, &c.

11. NOTATION.—The various chemical facts and reactions are concisely expressed in symbols, which generally are the first letter of the name of the element in English or Latin: each such symbol stands for 1 *atom* of the element, multiplied when necessary by a small figure following it a little below the line: all reactions are expressed by first writing in symbols the construction of the substances set to act upon each other, divided by +, and then the substances produced, and the two should exactly represent the total atoms engaged. There are many modes of expressing the same things in different formulæ according to the special theory of constitution adopted, or the particular view of the matter intended to be described: and there are two distinct systems in use.

(1) *The Equivalent.*—This system, used in all the old books, is based really on oxygen (which was called 100), and the weight of hydrogen which combined with oxygen being called 1, the equivalents of other substances were afterwards reckoned from this. Hence water is in this system called HO $(1+8=9)$.

(2) *The Atomic.*—This, which is called the "New Notation," is generally adopted in all modern chemical books. It is based on the fact that water contains two *measures* of hydrogen to one

of oxygen, and this being conceived to show the atomic relations, water becomes H_2O, and H being called 1 as to weight, it becomes necessary to call O = 16, and in consequence most of the metals have their weights similarly doubled as compared with the equivalent notation, while the number of atoms of those which are unchanged (the univalent elements) have to be doubled. The following example of the action of sulphuric acid upon nitrate of soda exhibits the two systems:

Equivalent.

$$\begin{array}{ccccccccc} \text{Salt.} & & \text{Acid.} & & \text{Salt.} & & \text{Acid.} & & \\ \mathrm{Na\ NO_6} & + & \mathrm{H\ SO_4} & = & \mathrm{Na\ SO_4} & + & \mathrm{H\ NO_6} & = & 134 \\ 23\ \ 62 & & 1\ \ 48 & & 23\ \ 48 & & 1\ \ 62 & & \end{array}$$

Atomic.

$$\begin{array}{ccccccccc} 2\overline{\mathrm{Na\ NO_3}} & + & \mathrm{H_2\ SO_4} & = & \mathrm{Na_2\ SO_4} & + & 2\overline{\mathrm{H\ NO_3}} & = & 268 \\ 23\ \ 62 & & 2\ \ 96 & & 46\ \ 96 & & 1\ \ 62 & & \end{array}$$

This means that the nitrate of soda on being mixed with sulphuric acid is decomposed into sulphate of soda and nitric acid.

12. FORCE.—Until recently the words force and energy were used indifferently in the sense of power; but they are now clearly differentiated, and *force* expresses causes, while *energy* expresses work, and capacity for work. But we must steadily keep in view the two uses of the word "force"; gravity, heat, capillarity, cohesion, electricity, &c., are called forces: but this is a remnant of the old habits; gravitation is truly a natural force, so far as we know, and all forms of attraction may be so considered; but the strict idea of "force" is that it is an expression which covers any agency which can generate a motion, or arrest or change its direction; for purposes of calculation it is, however, more strictly defined as the generator of "momentum" which includes mass as well as velocity, and this definition enables us to express the "energy" involved in any action in terms of unit force adequate to the production of that energy. We may regard force therefore as

I. Related to mechanical energy, or motion of matter as such, which, like gravitation, is connected with the absolute weight of matter in motion; its common unit in England is the foot pound: that quantity of force required to raise one pound weight one foot against the attraction of gravity.

II. Force related to the *atom* of matter. Heat does not act on matter by weight or by bulk, but atom by atom. This discovery has played a very important part in chemistry of late. Each element has its own atomic weight, and hydrogen, being the lightest, is taken as unity; thus the atom of iron weighs as much as 56 atoms of hydrogen, copper 63·5, silver 108, gold 197. If these relative weights of the several substances (being solids) are exposed to heat, and all raised to the same temperature, and are then each transferred to an apparatus capable of measuring the heat they have absorbed, it will be found that, different as are the quantities of matter in each case, they have all absorbed the same quantity of heat. Of course the experiment is so delicate and difficult that perfectly exact results cannot be obtained, and as different mechanical work is done in each case by difference of expansion, certain corrections have to be made; but the deduction is absolutely certain, that heat acts upon matter in its several physical states, not according to its weight, but according to the number of atoms it contains.

The relation of compound substances to heat is not so simple as that of elements, though still a distinct law is traceable throughout; each molecular form has its own relation to heat, which is due to the number of atoms it contains, and their state of combination.

III. Force related to the *molecule* of matter: such are the forces of electricity and magnetism which depend on the motion and polarity of the molecules. Heat also is related to the molecule in connection with internal work, such as expansion and resistance to pressure, and also as to the latent heat of fluidity: that is to say, there is a motion of the molecule as a whole, as well as a motion of the atoms within the molecule. Hence we learn that in the gaseous state, under the same conditions of force, all molecules, whether simple or complex, occupy the same space, so that heat and pressure produce the same amount of expansion or contraction upon all, proving that the force is acting upon the molecule as a whole, not upon its component atoms; and it is the same with the latent heat of fluidity, because the passage from the solid to the fluid or gaseous states is dependent upon the increased distance of the molecules, which neutralizes the attraction they exert on each other by causing them to move through wider spaces.

IV. Force related to matter in the form of ether. This includes light, and any forces known or not as yet generally known (for there are such), which are transmitted to us from the sun.

This classification appears very suggestive, as throwing light on many obscure subjects, especially when combined with the now recognized fact that all the forces are capable of transformation into each other; it enables us to conceive that if the undulations of the ether produce the effect which we call light, those same undulations, when transferred to the material atoms floating, as it were, in the ether, produce the effect we call heat; and thus we may apprehend the reason why heat and light are so constantly coexistent, and also see why it is that while the sun transmits us such a constant supply of heat as well as light, yet to all appearance the space between the sun and us is actually devoid of heat. In fact, we may consider that heat and light consist of the same motions, but heat is the motion of matter, and light the motion of ether; or else that they are the same in nature, but are perceived by different effects upon our senses.

13. **Energy.**—The idea conveyed by this term is replacing many of the old fluids, and functions of the ether: it is difficult to define, because such a name conveys the idea of some actual existence, as do the words light, heat, electricity, &c. But these are now seen to be not things, but actions, and energy is therefore a word which expresses the general agency of which these are but forms. Energy is really motion, or the capacity to pass into motion. Actual motion, whether mechanical or as temperature or sensible heat, &c., is called *kinetic*. The capacity to pass into motion, as where energy is stored in a strained spring, or in chemical decomposition or what used to be called "latent heat," is called *potential*. The doctrine of the "conservation of energy," which has played so important a part in modern science, teaches that "energy" is as indestructible and as impossible to be created as is "matter": that as in the various actions which occur matter is neither created nor destroyed, but simply changes its combinations and forms, so it is also with energy, which (derived from the sun) was stored up in effecting the reduction of water and carbonic acid to form wood or coal, remains "potential" and reappears in combustion, "kinetic" as heat, and passes by the aid of the steam engine into mechanical work; all of these being forms of energy having measureable relations to each other. This is in fact the counterpart of the doctrine of the co-relation of the forces. Energy, then, is the result and the measure of the action of force. By this enlarged view of force and energy we find the underlying truth which justified an old and apparently abandoned theory, for, in modern science, *energy*, or internal motion, is gradually assuming the position of phlogiston in the old chemistry.

14. **Electricity.**—The various theories of the nature of electricity are explained in their proper places. Here it will

suffice to say, that electricity is not a thing, but only a word, grouping together natural facts and ideas as to their cause, and that a great error is generally committed, even by eminent scientific men, by confusing distinct things under this one name; we speak of torrents of electricity poured forth from the thunder cloud, and from the dynamo machine, and in so doing we commit an error: we might as well class all the work done by hydraulic machinery, and the phenomena of the ocean, under the name of "water." Electricity comprises phenomena of two distinct orders, those of electric quantity, and of electric force; it is the first of these only to which the name electricity properly belongs, as compared to a thing, a fluid; as a matter of well-known fact electric quantity is very small in the lightning flash. The lightning is simply a case in which an enormous amount of energy is charged upon a small electric quantity. This "quantity" is in fact related to the molecular constitution of matter; it is manifested in chemical actions. We may find a very perfect analogy in hydraulic works, where force is transmitted and work done through the agency of water in pipes. Electric "quantity" may be compared to size of pipes or bulk of water transmitted, while electric "force" resembles the pressure put upon the water, as will be seen hereafter.

15. We not uncommonly hear of the "conversion of electricity into light, heat, or mechanical energy." This is an absolute error, originating in the confusion of the two factors of electricity. Electricity regarded as a quantity calls for two distinct expressions, Q, and Q^2. The first is strictly a quantity, and is that which the old theories considered to be material or analogous to matter, and represented to the mind by the expression imponderable fluid, but which the new theory considers to be numerical, the action of definite material quantities or molecules. This, which is properly the "electricity," can no more be converted into heat or anything else, than can the water in a steam boiler or hydraulic engine. The second, Q^2 is the electric energy, which is the true cause of electrical phenomena, and which may be converted into heat and work, because it answers exactly to the mechanical energy (also convertible) carried by the water as steam from a boiler, or under pressure in the hydraulic engine.

16. According to the theory adopted in these pages, electricity is not material or a quasi-material fluid, nor is it a special force; it is a form of motion; energy charged in a special manner upon ordinary matter, and developing special relations among its molecules. Since the first edition of this work was published, this view has gained much ground, and many things which then

were regarded as heresies, are now generally adopted as true scientific principles.

But while scientific men are fast coming to this view of electricity, and it is very commonly employed, more particularly in connection with dynamic electricity or galvanism, still the new theory is rarely fully set forth and substituted for the old fluid theories, and therefore it is very difficult for students to obtain that clear view of the subject which is desirable, especially as all the older terms of the science were devised in connection with the old theories, and are exceedingly ill-fitted to convey the new one without producing much confusion of ideas.

This work in its original form was intended to meet this requirement, and the plan adopted has been to commence with a few leading facts and principles, then describe the various forms of instruments necessary to examine the actions of the force, and by their aid trace out the general laws and fundamental principles of the science, after which the applications of the force of which the nature has been thus examined will become far more intelligible than by piling up isolated facts, or describing mere processes, however practically valuable.

To do this in a perfectly methodical manner is always more difficult in a natural science than in mathematical studies, because it is impossible to understand the most elementary facts without a considerable acquaintance with the subject; and, on the other hand, to lay a wide foundation in elementary facts before dealing with their theory would not fulfil the purpose of both leading the beginner in the best course and showing the more advanced how to adopt the new interpretations and to free themselves from the mental confusion produced by the old theories, while at the same time furnishing the practical man with the interpretation of the processes he employs.

CHAPTER II.

STATIC OR FRICTIONAL ELECTRICITY.

17. It is now generally admitted that mechanical motion is convertible into heat, and the effect of friction is a familiar illustration of this. For instance, if we turn a grindstone, it requires a certain force to start it, and then a certain amount to keep it in motion, to overcome the friction of its bearings and the air, and then so much more as is needed to overcome the resistance of any object we press against it, this body being heated in proportion to that pressure. If we get the stone into rapid motion, and then cease to work at it, it will run a certain time before stopping; but if we hold against it a piece of steel, it will come to rest in much less time, because its motion is absorbed by the friction, and if the stone is dry, we see a shower of sparks fly off, visibly exhibiting the transformation of this motion into heat.

But if we cover the edge of our grindstone with certain substances, guttapercha for instance, and establish certain other conditions, we can obtain a very different result; instead of heat we have electricity developed. When we ask, whence does this electricity come? the modern doctrines I am now setting forth teach us that it is like heat, the mechanical motion converted into molecular motion—that which of these forces we shall obtain depends entirely upon the conditions to which we expose the molecules, and further, that as soon as we allow the electricity to act, it either passes into heat, as we see by the spark, or else does some work which represents the heat.

18. This development of electricity by friction was observed in early days, and we derive the name itself from *electron*, the Greek name for amber; the substance by which the phenomenon of attraction after friction was first manifested. In later times it was found that many substances possess this property, and such were called "electrics," and those bodies which do not appear to possess it, "non-electrics." The distinction is more apparent than real; for under certain condi-

tions, both classes develop electricity under friction, the true cause of the difference being the different power of substances to conduct electricity, on which property is based another classification into conductors and non-conductors; but here again increased knowledge has shown that no such broad definition can be sustained, the distinction being one of degree only, not of essential property. All substances are electrics, and all conductors, though some conduct only very slightly. Faraday, finding that conduction was effected by "induction" of polarity from molecule to molecule, introduced the term *dielectric*, to convey this conception, and the term is commonly used now in the sense of a body which transmits electric induction, but chiefly as limited to those which do so slowly, or those which stand highest in the list of electrics. With this understanding of the meaning of the terms, as relative and not absolute, the classification has much practical value, and the following is a list of ordinary substances, in which, as we descend, each one is a worse electric and better conductor than its predecessor.

Electrics, Dielectrics, or Non-Conductors.

Ebonite.
Shellac.
Paraffin.
Guttapercha.
Amber.
Resins.
Sulphur.
Wax.
Glass.
Silk.
Wool.
Furs.
Dry paper.
Dry leather.
Baked wood.
Porcelain.
Dry ice, below 13° F.
Crystals containing water of crystallization.

Non-Electrics, or Conductors.

Oils in the order of their specific gravity.
Metallic oxides.
Smoky flames.
Vapours of alcohol and ether.
Rarefied air.
Living animals and vegetables.
Ice and snow, above 13° F.
Rain water.
Spring water.
Sea water.
Solutions of salts.
Dilute acids.
Powdered carbon.
Strong acids.
Plumbago or graphite.
Well-burnt charcoal.
The metals in order, silver being the best.

19. A distinction may be drawn among these substances, although the lines of demarcation cannot always be exactly defined.

Conductors are metals (also carbon in some forms) or substances of which metals, including hydrogen as a metal, form one of the molecular subdivisions or *ions*.

Dielectrics are substances not containing metals (except hydrogen, which in them does not replace a metal or form a separate constituent) and whose molecular constitution is complex.

In the former class electricity is *dynamic*, and the *conductive* circuit is set up: in the latter the *static* phenomena are developed, and the circuit is *inductive*.

20. STATIC ELECTRICITY is however a misnomer: it has no existence: all the phenomena are due to static strains, but there is always a gradual loss, called *leakage*, which is, however, the current due to the actual conductivity of all circuits; and every motion set up by so-called "static" electricity implies a transfer of energy, and action occurring in a field of force set up in the form of strains in the particular "inductive circuit" in which the motions occur.

21. We may now pass to experiments, from which alone knowledge is to be obtained. This is the only royal road, for mere reading will never give a knowledge of science. For this reason I shall indicate such simple forms of instruments as any one can obtain or make for themselves, but which will, if carefully studied, go far to demonstrate principles. The first things needed are a source of electricity, an indicator of its presence, and then the means of collecting it and examining its actions.

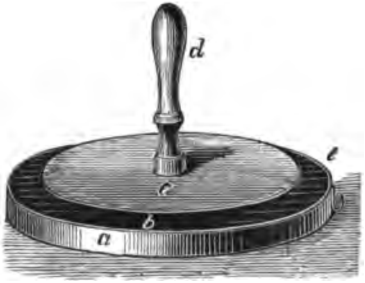
If we take a stick of sealing-wax, or a rod of glass, in one hand, and rub it with a piece of dry cloth or fur, we have the fundamental experiment from which electrical science grew, for we find that we have developed a force upon, or induced a condition in, the rod which enables it to attract and repel light substances, and the same effect may be produced by rubbing a vulcanite comb on the sleeve of a coat.

If we examine the conditions of this experiment by the light of advanced knowledge, we find they consist in the presence of (1) a dielectric in contact with (2) the conducting body of the operator; (3) another electric in similar contact; (4) mechanical motion, or friction of the two electrics; and (5) separation of them when the friction is ended. These conditions include every instrument devised for developing electricity by friction, and they may be applied in the simplest form.

22. THE ELECTROPHORUS.—This is the simplest source of electricity next to the mere rod; it has many forms, but its principles are the same as that of the rubbed rod. A common form is shown in Fig. 6. *a* is a circular tin dish into which is run *b*, which may be sulphur or any resinous substance. A cheap electric may be made with 8 parts of resin, 1 of shellac, and 1 of Venice turpentine or wax, well melted together and run into the dish *a*; *e* is a hook soldered to the tin dish, for convenience of attaching a chain as a conductor. The dish forms the

conductor from the dielectric to the earth, as the books tell us, but really to the body of the operator, who rubs the face of the disc with a piece of flannel or fur, or a silk pad covered with electric amalgam. A means of collecting the electricity from the surface is now required, and this is *c*, the cover, consisting of a piece of sheet metal, or smooth wood covered with tinfoil, and having a handle *d* of glass or well baked and varnished wood.

Fig. 6.



A very simple, and at the same time very effective mode of making insulating stands and handles, is to separate the surfaces by an air space, and leave only very small continuous surfaces. For instance, take a piece of stout glass tubing of half-inch bore and 4 inches long: make two discs of hard wood, or preferably of vulcanized fibre (as ebonite softens with heating), to fit tightly inside the tube, one disc being thick (say quarter-inch) and the other thin: now take a piece of strong glass tube or rod, of suitable length for the intended purpose, or a rod of wood prepared with paraffin, or even a metal wire or tube, according to intended use; make a hole in each disc to fit them on the rod, and with a file convert the disc into a star of 4 or 6 points: now force the rod and discs into the larger tube so that it enters a couple of inches, the thin disc being close to the end of the rod and half-way down the tube, and the thick disc just entering the tube, so that its outer parts may be filed off to a curve. Now warm the whole and dip it either in thin varnish or in melted paraffin. The open end of the small tube will receive wires attached to plates or balls; or it can be fitted permanently with any required apparatus. To convert this into a stand, take a block of guttapercha, ebonite, or prepared wood, with a hole in it to receive the stout tube. For adjustable stands, an upright rod of wood can be used, attached to a foot; pieces of tin or brass tubing, filled with a cork bored to fit the rod, will slide to required height and carry cross rods attached to them on which similar corked tubes will give any desired angular adjustment: such easily constructed holders are very useful for chemical and other uses; for electrical purposes they should be prepared with paraffin.

Wood conducts electricity, on account of the moisture it contains; for all electrical purposes it should be slowly and thoroughly baked without scorching, put into melted paraffin while hot, and kept there as long as any bubbling continues; it should then be removed, and as it cools, be dipped several times, so that the grain and pores of the wood become thoroughly filled up: in this state wood is a good insulator. Paper can be prepared in a similar manner.

A block of fresh melted paraffin makes a very excellent insulating stand.

23. It is desirable here to remark that glass, though one of the best non-conductors, has the property of condensing a film of moisture on its surface, and thus becoming a conductor. Therefore, those parts of electrical instruments which are made of glass, should, where possible, be covered with a varnish which has less attraction for moisture. This applies to the handle of the electrophorus cover, legs of insulating apparatus, and those parts of electrical machines which have not to be rubbed. The varnish should be moderately thin, so as to require several coats, rather than one of a thick varnish. A good cement is 1 lb. of shellac, dissolved in 1 pint of polisher's finish, with one-twentieth of its bulk of a solution of india-rubber in bisulphide of carbon, just thin enough to run freely. This forms a tough, coherent surface, and adheres strongly if the glass be warmed before applying it: it is also a good cement for joining glass.

Canada balsam also makes a very good varnish for this purpose, and probably a film of collodion floated over the glass, as in photography, is even preferable to a varnish.

Also in all electrical experiments, it is desirable to slightly warm the apparatus, and to work in a room the air of which is dry and moderately warm. When the air is moist, success is scarcely to be attained. Moist air is, however, not a conductor, as has long been believed: it is the deposit of moisture on surfaces which is the source of loss, as the water acts as a conductor. Ebonite also requires similar treatment, owing to the formation of an acid upon it: melted paraffin is useful as a coating rubbed over ebonite.

24. ELECTROSCOPES are instruments for evidencing the presence of electricity. Fig. 7 is the simplest form, being a glass rod mounted on a stand, and bent at the top into a hook, from which hang, by silk thread or hair, one or two pith balls. Fig. 8 is a more elaborate contrivance; it is a glass bottle; on opposite sides of the inner surface are pasted strips of tinfoil, which are continued to the outside and to a brass ring fitted

with a hook, to which chains may be attached. Through the cork passes a small tube, closed at the bottom, to which are fixed two strips of gold-leaf. The bottle should be well dried and warmed, and the cork cemented in and coated with shellac varnish; when the loose fittings *e* or *g* (Fig. 9) are inserted it is a simple gold-leaf electroscope; *f* is a metal plate covered with a coating of shellac on its upper face, and when this is fitted to the instrument and an exactly similar plate with an insulating handle placed upon it, we have a condensing electroscope. The lower plate is connected to the source, and the top of the upper plate touched with a conductor to "earth," such as the finger, just as in using the electrophorus, and for similar reasons: on removal of this conductor and then the upper plate, a far greater divergence of the leaves is produced than if the source had been connected to them directly, as will be readily understood by the explanations given in connection with Fig. 25, § 90.

Fig. 7.

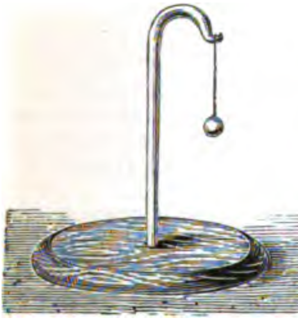


Fig. 8.

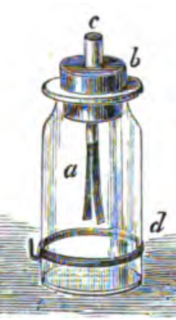
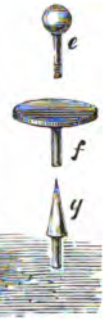


Fig. 9.



25. Connected as described, the leaves exhibit the same electricity as the source; the effect will equally be produced if the process is reversed, and the upper plate connected to the source, but then the leaves exhibit the opposite condition. The leaves diverge alike for positive or negative charges, but the nature of the charge is readily ascertained by rubbing a piece of ebonite, and approaching it to the instrument; if this is charged with +, the leaves will approach each other; if with − the divergence will increase; both effects are temporary, and cease when the ebonite is withdrawn; with excited glass the action would be reversed. A similar process is useful in testing feeble charges; if the electroscope is charged slightly with + electricity, when

approached by a + charged body the leaves will increase in divergence; on approaching a − body they will collapse.

These instruments only indicate the presence of electricity; to measure it electrometers are employed as described §§ 61–65.

26. One of our standard electrical works says (and it is just what all say), "*Vitreous* substances, such as glass, become electrical by being rubbed with certain other substances; in this state they attract light bodies. *Resinous* substances, such as sealing-wax and guttapercha, become also electrical when rubbed with certain other substances; in this state *they* also attract light substances. Bodies which have been once attracted by excited glass or excited resin will not be attracted by the same substance again until they have touched some body in communication with the earth, but will be repelled. A body which, having been attracted by an excited *vitreous* substance and is then *repelled* by it, is *attracted* by an excited *resinous* substance; so also a body which is repelled by an excited *resinous* substance is attracted by an excited *vitreous* substance."

These statements are received as absolute truth by electricians, and upon them the fluid theories of electricity are based; and yet there is scarcely a truth in them which is not overweighted by an error, and the simplest facts are misinterpreted.*

---

* One of the critics of the first edition of this work remarked, quoting this statement, that he was not aware "that the author had done anything to prove that he is able to sit in judgment on the intellectual giants among modern men of science. Mere off-hand condemnation of the laborious work of men like Sir W. Thomson and Prof. Clerk Maxwell cannot for one moment be tolerated." Those eminent writers were neither condemned nor named, and science would make poor progress if a thinker is to be debarred from the examination of theoretical principles advanced by any one, however eminent. The reason of these remarks, however, is that the author has only recently examined the posthumous work of that great electrician, Clerk Maxwell, published in 1881, and there finds that he was gradually abandoning the scholastic theory of electricity, and would apparently in due time have adopted the very doctrines taught in these pages. In his preface he says, "in the larger treatise, I sometimes made use of methods which I do not think the best in themselves, but without which the student cannot follow the investigations of the founders of the mathematical theory of electricity. I have since become more convinced of the superiority of methods akin to those of Faraday, and have therefore adopted them from the first." The theory advocated in these pages is the direct outcome of Faraday's investigations and teachings, and its methods of putting questions to Nature, instead of creating an artificial oracle from mathematical abstractions, is that of Faraday, who never troubled himself as to those formulæ which, as he said, were the affair of the mathematicians. Now what says Clerk Maxwell as to the movements set up by electricity? He describes the electric field, in which are lines of force, with an electromotive force acting in one direction along those lines; speaking of a suspended pith-ball, he says, "it will move under the action of a new force, developed by the action of the electrified ball on the electric condition of the field." "If the charge is positive, the force which acts in the ball is on

27. Let us examine this matter of attraction and repulsion, by the aid of the simplest experiments, which every one ought to perform for himself. Our vitreous substance may be a piece of stout glass tube. (N.B.—It must be kept warm to get any good effect.) For our resinous substance we take a piece of ebonite, the very best and strongest electric; the back of a comb will do, or a slip cut out of a thick sheet. A silk handkerchief is the readiest exciter, or a piece of flannel will do very well.

A convenient electroscope consists of a tube of glass upon a foot; in the tube is placed a brass rod with a tube across its upper end, in which slides a wire, one end finished with a lump of guttapercha or glass bead, and the other with a hook, for the pith ball or balls. Let a pith ball be suspended by a dry hair or silk fibre, and the excited electric be presented; the ball will be first strongly attracted, and then steadily repelled; but

---

the whole *from* the positively electrified body and *towards* the negatively electrified walls of the room." Here we have no word about a repulsion between the similar electricities; the explanation of repulsion and of the part played by the connection to "earth" are identical with the teaching of this work; as we proceed, further instances of this will arise. It may be properly remarked here, that in a discussion on the subject of "potential," in which several eminent electricians took part, and in the course of which the author first described potential and electromotive force as simple mathematical expressions for the square root of the energy involved, Prof. Clerk Maxwell said, "If we were to restrict our attention to electrostatics it might be convenient to use the phrase potential difference instead of the ordinary phrase, electromotive force, but in other parts of electrical science we have to deal with electromotive force in cases where potential, and therefore potential difference are words without meaning." In the course of the same discussion, another eminent rising electrician of the mathematical type, Dr. O. Lodge, in attacking the position maintained by the author and Mr. D. G. Fitzgerald, said, "They would say, it is impossible to give a system of bodies an absolute charge of either positive or negative electricity; in other words, wherever there is a positive charge there must be an equal negative charge somewhere else, connected with it by lines of force. True! Again they would say, the really active agent in electro-static phenomena is the polarized dielectric in which the state of strain exists; and the conductors, one at each end, are simply breaks in the continuity of this dielectric, enabling the phenomena called *charge* to appear at the bounding surfaces. True—most true." Here again we have the doctrines taught in these pages, which are still untaught or very partially accepted in the textbooks endorsed by those who belong to the opposite school. The object of these remarks is to give confidence to students in considering explanations different from those usually given, and to show them that instead of being mere heresies they simply mean, that in the words of another critic (who still objected to the doctrines taught as to repulsion and the electric field), the author "has boldly accepted the doctrine germinated by Faraday and *slowly creeping into scientific belief* that electricity and magnetism are due to the polarity of molecules, and that we are to search for it not so much in the conductors that bring it within the cognizance of our senses, as in the insulating media that are inseparable from its manifestations." The heresy of to-day is very often the orthodox faith of the future.

if an excited electric of the opposite order be presented it will attract the ball, and then, if capable of reversing its charge, will repel it.

Hence it is stated, as a fundamental law, that bodies similarly electrified repel each other, *which is not true*, so stated. Moisten the suspending fibre slightly, or substitute a ball suspended by a very fine wire, and no *repulsion* will occur; the ball may be led up above the stand, and the electric raised slightly till a point is reached at which the ball will float as it were in the air, the attaching fibre hanging loose, apparently having nothing to do with the ball, which thus acts the part fabulously attributed to Mahomet's coffin. Why does repulsion occur in the one case and not in the other? If the excited electric be held over a table on which are laid some loose pith balls or pieces of paper, &c., these will fly up to it, and back to the table, rapidly repeating this process till the electric excitement is considerably reduced, or till the electric is taken farther away; then the light bodies will firmly adhere to its surface. If the supposed repulsion really existed, it is obvious that these bodies, which are of course similarly electrified by contact with the electric, *could not be held* firmly to it. If the electric when excited be placed apart from all surrounding bodies, in a dusty atmosphere and in a beam of light, it will be seen to attract the floating particles and hold them without at all repelling them after contact. In fact, the repulsion is only apparent, the real cause of the motion is to be found in the attraction exerted by the surrounding bodies.

If two balls are suspended side by side and touching, by dry hairs, they act like the single one, first touching and then flying from the electric; on removing this, they fall together, but will not quite touch; they apparently exert a mutually repulsive action, which increases on the approach of the electric, and also if on each side an unexcited body is approached. If, while the balls are separated by this apparent repulsion, an excited electric of the opposite order is brought near, they will fall together: the hand which holds the charging electric itself, or a finger of the other hand, will also act as an electric of the opposite order.

These experiments may be varied in almost endless forms, and the actions noted with various suspending fibres, and with the stand of the electroscope insulated or connected to earth. They will be found described in most text-books, and will not be described here for that reason, and also because it is not the purpose of this work to go further into the subject of static electricity than is necessary for the examination of its leading principles; those who wish to study it thoroughly will do well to follow the smaller work of Clerk Maxwell, bearing in mind however, that many of his explanations were written while his mind was in a state of transition, as shown in note to § 26. A still more exhaustive study of the subject will be found in 'Accumulation and Conduction of Electricity' by F. C. Webb.

28. **THE TWO-FLUID THEORY.**—When it was found that the electric excitement produced on glass was opposite in its nature to that on amber and resins, the earlier experimenters concluded that there were two "fluids" pervading matter; that each of these fluids exerted a strongly repulsive action on its own parts, or bodies charged with itself, but that each fluid had a strong attraction for the other, and both a strong attraction for ordinary matter; also, that in the ordinary condition of matter, the two fluids were united in equal proportions, being thus neutralized and adherent to matter. Some have supposed that the two fluids when thus united constituted another hypothetical fluid, caloric, or heat.

It was supposed that by friction of some substances, thence called electrics, these two fluids were separated, the one remaining on the surface of the electric, the other on the rubber, and that from these either could be transferred to insulated bodies, that is, to substances which furnished no pathway along which the disunited fluids could find a way to the reunion intensely sought by both. Hence, when a charged body or an excited electric is presented to a light movable body, the latter is drawn towards it by the attraction of the fluid for matter; as soon as the charge is equally divided, the self-repulsive property of the fluid causes the bodies to repel each other; and then if a body similarly charged with the other fluid is within reach, attraction occurs, the fluids reunite, with a spark if the quantity and tension are great, and resume their usual neutral state. But if there is no such oppositely charged body accessible, any body in conducting connection with the earth will enable the charge to dissipate itself, as some say, because the earth is a comparatively infinite reservoir of both fluids, but more simply and more in accordance with the theory itself, because it presents an unlimited surface and body of matter; and the fluid distributing itself over all surfaces and matter to which it has a conducting path, the charge, which is great upon the small surface of the electrified body, becomes nothing when it has the whole earth to spread itself over. This hypothesis was built upon the phenomena of frictional electricity, and of these it furnishes a moderately satisfactory explanation.

29. **THE ONE-FLUID THEORY** was devised by Franklin, as more simple than the other. He supposed that there was one

electric fluid pervading all matter, possessing a strong attraction for matter, but being strongly self-repulsive: matter in its ordinary state has in connection with it so much fluid as satisfies the mutual attractions, but when certain bodies (electrics) are rubbed, some absorb part of the electricity from the rubber, and thus become *positively* charged with this overplus; others part with their proper electricity to the rubber, and thus remain themselves *negatively* charged. As with the other theory, the earth is supposed to receive the electricity driven off, or to supply any quantity of it when needed. This theory also explains the ordinary phenomena of static electricity, and on it Berzelius built his electro-chemical theory, which ruled chemical science for many years, treating the relative affinities of different substances as due to the relative proportions of electricity belonging to them.

30. All the terms of electrical science have grown up from these theories, and hence we have

$$\left.\begin{matrix}\text{Vitreous}\\ \text{Positive}\\ +\end{matrix}\right\}\text{and}\left\{\begin{matrix}\text{Resinous}\\ \text{Negative}\\ -\end{matrix}\right\}\text{Electricity:}$$

also the words charge, quantity, conduction, accumulation, and distribution, which imply the passage of something having a real separate existence; these and similar terms we are obliged still to use, but I will define the meanings they are to convey in this work. The last terms and their signs will be those used, as they are generally known, but they will not be used as conveying the idea of an excess or deficiency of a fluid, but simply as expressing opposite polarities of matter.

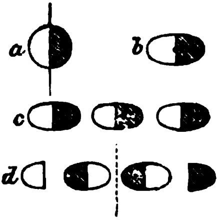
31. The Molecular Theory was founded by Faraday in his memorable experiments on induction, but it has since grown with the growth of the other sciences; it is a necessary sequence to the now established doctrine of heat being motion, and is intimately connected with the more modern and rapidly advancing doctrines of chemistry. Simply stated, it is, that electricity has no existence as an *entity*, but the phenomena we call electrical are due to properties and motions of the molecules of matter, to comprehend which we must now return to the consideration of the molecules themselves and their mode of arrangement into the usual forms and substances known to us. Of late there has been a tendency to attribute the actions of electricity to motions of the supposed ether (see § 5), which is considered to be in some way condensed upon the material molecules: this idea is naturally most favoured by mathematicians; it is unnecessary to consider it, and to all but trained mathematical minds it is nearly incomprehensible, and appears

only a modification of the old one-fluid theory: if the ether is so condensed, it becomes a part of the material molecule and the cause of its actions, and therefore all that is really known can be studied by considering the molecule as possessing certain properties now to be studied, leaving in suspense, as beyond our present knowledge, the cause of those properties.

32. Our former consideration of the molecule (§§ 8, 9) related to its chemical constitution. We have now to examine its physical character, internal, as regards the manner of its existence and breaking up, and external, as to its attractions for and relations to other molecules; and we have to consider it as a body composed of two distinct parts linked together, but acting also as a whole from a common centre. Tyndall's words when describing the actions of light, heat, and pressure on gases, convey the idea very fully:—"Molecules do separate from each other when the external pressure is lessened or removed, but the atoms do not. The reason of this stability is that two forces—the one attractive and the other repulsive—are in operation between every two atoms, and the position of every atom—its distance from its fellow—is determined by the equilibration of these forces." "The point at which attraction and repulsion are equal to each other is the atom's *position of equilibrium*. If not absolutely cold—and there is no such thing as absolute coldness in our corner of nature—the atoms are always in a state of vibration, their vibrations being executed across their positions of equilibrium."

This means that the internal attractions of matter draw the atoms together; the forces of heat, &c., as motion, tend to separate them; and (the molecule being constituted by the balance of these forces) additional force tends to separate the atoms, and break up the molecule. We may now simplify our conception by Fig. 10 *a*, in which we represent the two halves of the molecule as vibrating, under the influence of the undulations of heat, on a central point and vertical line.

FIG. 10.



Now suppose a force exerted which either intensifies those oscillations, as, for instance, heat, or which sets up a revolution of the entire molecule on the same centre and line, the effect would be to alter the molecule to Fig. 10 *b*, in which it is obvious the internal attractions are weakened. If we now conceive a line of such molecules, Fig. 10 *c*, we see that there must come a time when the atomic attractions will be greatly weakened internally and partly exerted on the corresponding or complementary parts of neighbouring molecules. In this state the substance may be said to be *polarized*. The degree of this tendency would be called its tension, being the strain upon the attractive forces; as this increases there comes a period when the molecules break up and re-form, as shown in Fig. 10 *d*. This will be a discharge. The extreme atoms here may be considered either as forming parts of a continued chain, or as set free.

Faraday's theory of induction by polarization of adjacent molecules, though the origin of this conception, is very different from it; he was treating of the actions of a body charged with one kind of electricity, and the mode in which it produced electrical actions on surrounding bodies, but later discoveries have developed that theory of the *effect* of electricity in the form of charge, into a theory of the *source* or *cause* of electricity itself: this theory, which is the one adopted in this work, may be thus defined.

Electrical action is developed only when a complete chain of polarized molecules can be formed. When that chain is wholly composed of conducting molecules, dynamic electricity is manifested; when the chain is partly composed of non-conducting molecules, we have static electricity. The distinction between the two is the presence or absence of the conditions of discharge. (See also § 40.)

33. We are now ready to examine the conditions under which, and the reasons why, friction developes electricity; and first, one glance at the utter improbability of the "fluid" explanation of this. The fluids have a strong attraction for each other and for matter, yet the rubbing of two substances together is sufficient to separate the fluids from each other, and the matter with which they are in quiet union. They have a strong repulsion for themselves, yet, in addition to overcoming these attractions, we collect these self-repulsive fluids into separate reservoirs. At the instant of doing so these reservoirs are in actual contact, yet the fluids do not reunite there, though they will do so with great violence when again brought into somewhat near neighbourhood, and travel any distance to get the opportunity. In fact, at the point of origin the fluids must actually transform their mutual attractions into repulsions. Looked at thus, it is obvious that such theories could only have been formed in the determination to make some kind of explanation of striking phenomena newly discovered, and that they have held their ground simply from habit and the gradual training of every one's mind to study the phenomena only by means of them.

34. Whenever two solids or a solid and a liquid are rubbed

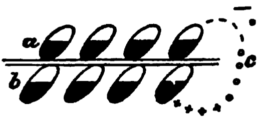
together, electricity is developed; gases do not appear to produce this effect, but we need attend now only to the special phenomena of ordinary electrical excitement. We have hitherto treated glass as becoming positive by friction, developing vitreous electricity, but this is not an absolute fact; if, instead of a piece of silk for a rubber, we use a piece of cat's-skin, the glass becomes negative. The exact relation between various substances is stated variously by different experimenters: the following list (given in Ganot's 'Physics,' and probably the most correct) shows the bodies which when rubbed together develop positive electricity in the first and negative in the one which is lower in the list:—

+ Cat's-skin.
Glass.
Ivory.
Silk.
Rock-crystal.
The hand.
Wood.
Sulphur.
Flannel.
Cotton.
Shellac.
Caoutchouc.
Resin.
Guttapercha.
Metals.

We may certainly deduce from this list, that the nature of the substances in friction has a great deal to do with the result, and probably the most complete examination into this point was made by Coulomb, whose conclusions were, that those bodies whose parts are least disturbed by the friction tend to become positive, particularly if compressed; those which are most disturbed become negative, especially if dilated.

35. This implies simply that molecular disturbance is the cause of the electricity; and the deduction is very plain, that when two dissimilar substances are rubbed together, a certain amount of adhesion is produced, and adhesion is attraction of a nature closely resembling cohesion; it is simply an external attraction, as cohesion is an internal one. This attraction, therefore, is to some extent opposed to the natural state of the bodies; it tends to draw the superficial molecules away from their neighbours; the opposing or complementary halves of these tend to unite, and therefore the internal attraction of the molecules themselves is weakened—they are polarized; Fig. 11 conveys an idea of this effect. The superficial molecules react on their neighbours; and a complete chain of excited polarized molecules is formed, along which is transferred the energy which but for the friction would have generated increased motion. It does so still, but if there be no resistance it produces that which we see and familiarly call motion; if there is resistance, we have the motion among

FIG. 11.



the molecules, which is electricity, and this again exhausts itself by transmission to neighbouring matter in the vibrations of heat.

Here we have a simple theory which unites Static and Dynamic electricity, and explains alike the excitement by friction, contact, chemical action, and heat. All are due to calling into action the latent attraction between what for convenience we may call the + and – atoms of *different* molecules, thus weakening the + and the – attractions *within* the molecules. This theory also includes in one the two long-contested theories of dynamic electricity, the Contact and the Chemical.

36. Now, returning to Fig. 11, let the line of dots *c* represent the molecular chain, which is shown variously formed to convey the idea of the different substances which may compose it. If we separate the two surfaces, the intervening air is polarized, and keeps the chain complete. Readers will now see the explanation of the experiments § 27. When we rub the electric the chain is formed through the body. On separation it completes itself through the air, showing the one hand holding the electric +, the other hand – or the reverse. On presenting the electric, the ball, coming within the circles of polarized molecules, is itself polarized and attracted. It then sets up its own circle of polarity through its suspending fibre, supporting rod, down the stem and across the air, and hence all the resulting phenomena of attraction and repulsion; for this reason also the results are so different when the suspending fibre is non-conducting or conducting, inasmuch as on that depends the road through which the effort to discharge must be made.

37. The foregoing remarks show the new meanings which, in accordance with this theory, must be given to the old terms of tension and discharge. Polarization already bears this meaning, though it has also been applied to some other phenomena. But though "discharge" is described as the breaking-up and re-formation of molecules, it is most probable that it includes another process. This is the simplest to conceive, and is certainly that which occurs whenever chemical action takes place, and probably, therefore, in all passages of electricity through liquids. But it is possible that the molecules transmit the motion without being themselves broken up. We do not understand yet what *cohesion* is, but it is certainly an attraction between the molecules, acting from their centres, in a manner analogous to the action of the atoms on each other; hence we may readily perceive the probability of another kind of polarization, consisting of a tendency to form groups of

molecules, and to effect discharge through the extra-molecular forces of cohesion, instead of through the atomic or chemical attractions *within* the molecules. This subject has not as yet been examined, and indeed the task is a very difficult one, though it will well repay those who have the power to examine it, for here may possibly be found the explanation of the differences of action of electricity on different bodies, and their relative conductivity as depending upon the forces either of atomic attraction or molecular cohesion, and the energy required to overcome either of these according to circumstances. The same explanations and the same diagrams will however equally convey the idea whether we consider that Figs. 10 and 11 represent the single molecules breaking up, or groups of molecules doing so, because the figures are not pictures of the things themselves, but merely an endeavour to realize ideas as to their actions.

Another mode of transmission is by rotation of, without actual breaking up the molecules, which evidently occurs in liquid conduction and probably in all conductors in a spiral path along the conductor.

38. The fundamental laws which experiment has thus far developed are:—

(1) *Electrified substances attract neutral substances, and then under certain conditions repel them.* They do so by polarizing their constituent molecules, and then, if the electrified body be in a + condition, attracting the – side of the attracted substance.

(2) *Substances dissimilarly electrified attract each other.* That is, bodies, the external molecules of which present, one their + extremities, the other their – extremities to each other, are mutually attractive.

(3) *Substances similarly electrified repel each other.* That is, there is no attraction between the two molecules presenting their + or – extremities to each other, and they repel each other apparently; but not owing to any real repulsion.

These are the ordinary electrical laws (for a scientific *law* means the statement of a natural fact), interpreted according to the molecular theory. Their full meaning will be seen when the nature of the "inductive circuit" and the action of a field of electric force have been studied.

39. The action of the electrophorus will exhibit many of the principles of electrical science, though we cannot obtain from it any very striking effects like those of powerful machines. A very convenient and simple form consists of a glass and an ebonite disc (the glass merely for noting differences of action),

provided with a cover like Fig. 6, and a stand of wood somewhat larger than the discs. The wood should be thoroughly baked, well covered with shellac varnish, or treated with paraffin as described § 22, and supported by three feet of ebonite rod or guttapercha to form an insulating stand. The upper face should be covered all over with tinfoil, connected to a small hook or ball screwed into one side for attaching conductors to. On the edge of the face should be three studs or pieces of wood to hold the disc in its place when rubbed. These stands serve also for many experimental purposes, and may be used as an artificial "earth." To use the apparatus for examining the principles of the electrophorus, place the ebonite disc on the stand, rub it well with a silk handkerchief and apply to its face a *proof plane*. This is simply a miniature cover, a piece of metal or wood covered with foil, and mounted on a glass handle; it is well to have a variety of these of various forms and sizes, providing them all with a piece of tube or a wire at the back, to slip on a glass handle or a stick of shellac. On touching the ebonite with this and presenting it to the pith ball electroscope it will be found that there is no action. Now this may arise from two causes, and therefore the principle must be examined.

40. It is generally considered that when an insulated body touches a *charged* one, the two become one, as far as the electricity is concerned; that this distributes itself over both surfaces, and when these are separated each is supposed to retain its proportionate share of the "fluid." The proof plane is so employed in many cases, but it acts differently on the electrophorus, a fact which throws great light upon the true but ill-understood nature of "Charge." The electrophorus is apparently, to all intents, a charged body, for its face, if resinous, is in a purely negative or — state, yet if we apply the proof plane and remove it we shall only discover a faint charge by very delicate instruments. To obtain electricity on the plane we must touch its upper face with a conducting body, in what is called "connection to earth"; practically the operator's finger will serve, but for the sake of theory the connection should be a piece of wire attached to a chain, which drops on the floor, or is hung to a gas-pipe. This is also the way in which the electrophorus is used for any purpose; in order to charge it by friction, the back of it, whether this be a metal dish in which it is cast or the foil on the back of a disc lying on the stand described § 39, must be "connected to earth"; this means, as in all other cases, that it must be *connected to the rubber*; without this no charge is generated; but this circuit being made (either by the chain

described or by the operator touching the back of the instrument if insulated) it is excited by friction, the cover placed on its face and touched on the upper surface with the finger, to make connection to the back; the cover when now raised is found to be charged, and sparks may be drawn from it. The instrument, when excited, will retain its powers for a long time if the cover be placed on it; in a dry air it may retain its charge for days or weeks, ready to give a spark without fresh excitement.

A reference to Fig. 11, p. 27, will explain the conditions. The lower line of molecules *b* may represent the excited disc, and the upper row *a* represent the rubber during excitement, and the cover when in use. The mass of the dielectric becomes polarized, and the essential property of these dielectrics is to retain this condition of *stress* in which energy is so charged upon their molecules as to constitute a field of force within them, having a strong resemblance to the magnetic conditions. In order to set up this field of force and state of stress, the primary condition is that there shall be a completed circuit (§§ 21 and 32). If the connecting chain *c*, Fig. 11, is removed, we find the electrophorus which it represents will receive no electric charge, but friction would heat it: if, to use the old phrase, we connect the sole plate to earth, with which the rubber is also connected through the body of the operator, we have electricity instead of heat, that is to say we have *potential energy* stored as stress in the molecules of the dielectric, ready to produce the phenomena of electricity, when the proper conditions are present. If we now place the cover on the face, without connecting it to the back, the cover simply replaces a stratum of air, and it has on its upper face a charge of the *same* order as that of the face of the electrophorus, *while lying on it*, but no charge at all if removed. Its conditions are exactly the same as those of a cylinder brought within the "inductive field" of a charged body, § 87. It is simply "polarized," + on one side and equally − on the other. But if we close the circuit *c*, Fig 11, new conditions arise; if the cover were in perfect contact with the dielectric, discharge would occur, for then the conditions would be identical with those of the Leyden jar. But in fact the cover only touches a few parts of the surface; the conditions are more comparable with those of a magnet when its armature is placed on its poles; the consequence is that when this circuit is broken by removal of the finger, or otherwise, the cover assumes a state *opposite* to that of the dielectric, because now it really continues the polar order of the other side of the dielectric to which it had been connected. The old explanation was that − charge of the face *induced* a + charge on the cover as it approached, and that the corresponding − of the cover went away into the earth, and then the opposing + and − charges *bound* or *dissimulated* each other, all which is needless complication. There is an attraction between face and cover, as there is between magnet and armature, in which latter case we have what might equally be called, bound or dissimulated magnetism; in both cases also the removal of the attracted body, against the force of attraction, restores the energy expended in setting up the polar force. The cover on removal has an apparent charge of free + electricity; but in fact, as long as it lies on the plate it is in the line of the external circuit of the plate to its sole, and on removal, it divides that external field, setting up fresh lines of force to all surrounding objects, until it approaches near enough to some object in which these lines of force can concentrate, when discharge of this local field occurs as a spark. The required connection to the sole or other side of the dielectric is frequently made by a pin coming through the mass of the electrophorus, with which the cover makes contact at once without any special process: this disposes of any theory calling forth the agency of the "earth" as a reservoir and sink of electricity, because the instrument acts just as perfectly when insulated as when connected to earth; so also do electrical machines when their rubbers are insulated and connected to the outer coating of a Leyden jar while charge is given to the inner coating from the prime conductor.

41. In working for discovery it is requisite to experiment first and then seek the interpretation, and this is a good mode of instruction also; but, on the other hand, an experiment, and, still more, a description of one, is far more intelligently studied when its object is understood; and for this reason, before proceeding to the details of the laws and experiments of charge, it may be well to first explain the general principles, although to understand them fully, requires acquaintance with the details which will follow. The expressions of most electrical writers are such as to justify the common notion that either positive or negative electricity is capable of separate existence, isolated from, and independent of, its opposite. Yet all admit this general law.

(4) *One electricity can never be produced without producing at the same time an equal quantity of the other.*

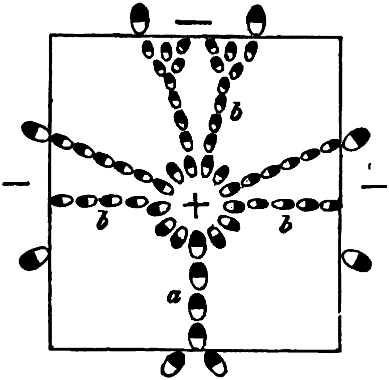
Thus, in friction, if the electric be +, the rubber is −; so also in a battery, one extremity is +, the other −; and in a

Leyden jar if the inner coating is positive, the outer is negative. All theories include this law, because it is a simple fact; but it is an inevitable consequence of the molecular theory, for the molecules necessarily have two opposite sides, and the reactions of these sides are the causes of the phenomena. But the fluid theories assume that, having produced separation of the two electricities, one of them may be dismissed into the earth as the common reservoir, or infinite conducting surface, leaving the other free and isolated.

42. **Earth Connection.**—This assumption is attended with many difficulties, all of which the molecular theory disposes of by doing away altogether with the supposed function of the earth, which really acts simply as any other conductor does in dynamic electricity, and has nothing at all to do with static electricity. The "earth" connection is, in fact, nothing but a junction common to all the circuits which may be connected to it: it should be regarded as a zero or common binding screw.

As we usually work an electrical machine, we must lead a chain from the rubber to the floor or gas-pipe, or else we can obtain only a very slight effect. Hence the idea that we make a connection with the mass or surface of the earth itself. But what we really do is to form a connection, by means of moderately good conductors, with *the walls of the room.* The effect is to produce a large surface polarized under feeble tension, and then the whole of the air in the room is polarized and completes the electrical circuit. The room becomes, in fact, a large Leyden jar, of which the dielectric *air* represents the glass. The charged bodies or prime conductor form the inner coating, and the walls of the room the outer coating. Thus, when another insulated body touches the first, it does not, as generally supposed, take part of its free electricity. It simply enlarges the "inner coating," and, of course, in doing so proportionately lowers the "density" of the charge, that is, the number of lines of force upon a given area.

Fig. 12.



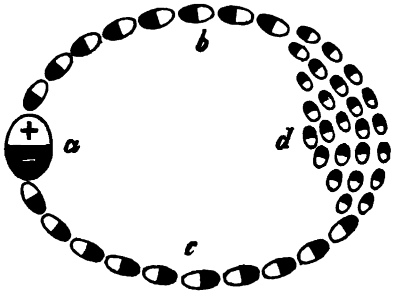
43. **Surrounding Surfaces.**—Fig. 12 represents this. + is the

charged body, with all its molecules presenting their + extremities outwards; *a* is the earth connection conveying the polarization to the walls of the room, which are thus rendered −, and *b b* are the molecules of air completing the chains. This explains why any one at all near an electrical machine in action experiences a peculiar tingling sensation. His body is in the path of polarization, and as he is a better conductor than the air, a good part of the circuit is concentrated in his body. All the small superficial hairs rise and point on one side to the nearest wall or other bodies, and on the other with still greater intensity to the machine. This happens even if he is insulated, but if he is in some degree of electrical connection with the walls and floor, the nearer he stands to the machine the more he represents the outer coating. He is, in fact, electrified, not, as might be supposed, by the machine and with the electricity of the conductor, but with the opposite, because he completes the polarized chain, while, if insulated, he will be + on one side and − on the other. Hence we find,

(5) *The other electricity is, in equal quantity, distributed over another surface separated from the first by a dielectric in which there exists a field of force due to these two equal opposite charges.*

44. INDUCTION.—This term is so frequently employed in electricity that it is necessary to define fully the idea it is intended to convey. Generally it may be said, that any molecule when "polarized" *induces* all others within its influence to follow its example, that is to say, employing the true meaning of the word, it *draws them* into the same systematic order: in like manner a magnet *induces* magnetism in neighbouring bodies susceptible of becoming magnetic, and an electric current *induces* a current in neighbouring conductors. This power results from the constitution of the molecule, as defined § 32, when under the influence of "polarization," which directs a portion of its constituent energy externally.

FIG. 13.



In Fig. 13 *a* is the primary molecule, whence the polarizing force acts in both directions and on each side, *inducing* its neighbours to turn towards it that side for which it has the greater attraction. Thus its + side acts on the molecules *b* and its − on the molecules *c*, seeking on each side the most rapid and shortest course to complete its chain. The collection of molecules *d* represents the passage from a good conductor into a dielectric, as from a charged surface into air, where the energy is distributed over a number of chains.

But the idea of induction has been much misapplied. Thus, since it has been recognized that on bringing a surface near to a charged body, a charge of opposite name appears upon it, this charge is commonly said to be "induced": so also is the charge on the surrounding walls said to be "induced" by the charged body. This is a consequence of the error as to the action of the earth; first we are supposed to separate neutral (+ −) and place + on the body while driving − into the earth, where it departs to somewhere about Australia as a recent book explains: but then this + objecting probably to its solitary existence, "induces" another − charge to keep it company on the walls; whether it is the same − come back from Australia is not explained. But this is not induction; it is the primary act of charge—a dual action. The term "induction" is only properly employed when a change of circuit occurs, and it is the process by which a new field of force, in another inductive circuit, is set up.

It is desirable to describe now, the more powerful sources of electricity and the means of measuring it, before further following out the theoretical principles: but I do not propose to occupy space by describing instruments which are fully described in all the text-books; it is not likely that this will be the only book accessible, and therefore it is better service to my readers to refer them to others as to such universal and simple matters, and occupy space here with subjects they do not find in every other book. When dealing with such subjects, it is because they form part of a necessary line of examination, or in order to furnish information which may assist readers in making the instruments for themselves.

45. **Electrical Machines.**—Static electrical machines may be divided into two distinct classes.

(1) Frictional machines, in which the electric is constantly excited by friction and as constantly discharged into a reservoir of force; this class includes the plate and cylinder machines.

(2) Induction machines, which operate on the principles of the electrophorus. The electric is excited by friction at the commencement of operations, but is not itself discharged; there is no continued friction, or only sufficient to sustain the charge,

but successive actions of inductive charge, and discharge into a reservoir are effected.

46. FRICTIONAL MACHINES.—The principles of the frictional machine are those laid down § 21. There is (1) The electric to be excited, the plate or cylinder. (2) The exciter or rubber. (3) The mechanical motion generating friction. (4) The circuit of polarization, which here includes the "separation," because part of it must be non-conducting. (5) The reservoir of force—the prime conductor, as it is called, but which is strictly a part of the circuit of polarization, though most conveniently considered separately.

I. *The Electric.*—This is usually glass, in which case the charge from it is positive. Guttapercha may be used, and has been employed in the form of a band stretched between pulleys: electrical machines have been thus generated unintentionally in manufactories where guttapercha belting is employed, and some fires have been caused by sparks given off from such belts running over wooden pulleys. The best electric of all is ebonite, but its surface roughens and deteriorates after continued friction. It is subject also to the formation of a film of sulphuric acid upon its surface, owing to the action of the ozone which is produced when the machine is worked, and which is the cause of the peculiar smell perceived: for this reason it is desirable to coat with shellac all exposed ebonite surfaces not to be exposed to friction. Glass is, however, the electric usually employed, because it is cheap and enduring; it has, however, the great drawback of condensing moisture on its surface; as to which see § 23.

The hardest glass, containing most silica, is best; crown glass, such as window sheets are made of, or that from which common pale green coloured bottles are made, is better than flint-glass. A cylinder machine may be made of a large bottle, if one is selected with straight sides and polished surface; a rough surface does not generate electricity well, as only the salient points come in contact with the rubber.

II. *The Exciter or Rubber.*—This part of the instrument should present as large a surface as possible to the electric; in a cylinder it should reach within an inch of the ends, and in a plate machine to a moderate distance from the axis, so as to utilize the surface as much as possible; it is best made of a tough but soft leather, well stuffed with the best horsehair to give a firm and even but elastic pressure on the surface; it should be insulated carefully, but be itself conducting, and provided with the means of connection "to earth" or to apparatus. These principles can be carried out thus. The face of the rubber is covered with amalgam, and on the edge from which the motion approaches the rubber a slip of stout tinfoil should fold over slightly to make a connection between the amalgamated face and the metal back or conductor, and from the same edge should fold over a piece of soft silk, forming the real face through which the amalgam finds its way, and acts much better than when it is freely in contact with the glass. From the other edge of the rubber extends the flap, which covers the surface of the glass where excited, and reaches close to the points which take the electricity to the prime conductor. It should be made of good stout black silk, sewed to the edge of the pad so as to touch the glass directly it leaves the pad, and outside the black silk should be another, slightly smaller, of oil silk. In a cylinder machine this flap is simply a straight piece lying on the glass, but in a plate machine it is cut to the shape of the disc.

III. *The Mechanical Motion.*—This includes the mounting from which the motion is to be imparted. Either plate or cylinder is to be firmly mounted on an axis; for small machines this may be of hard wood, thoroughly baked and saturated with paraffin; in larger instruments this axle must be of metal, in which case it must be carefully insulated in every possible way. The best way of securing a plate to its axle is to have two loose collars of prepared wood fitting tightly on the axle, and thick enough to take firm hold of it; the plate is fixed between these, and all the surfaces being well supplied with shellac varnish, all the parts are compressed together till thoroughly set and then covered over with several coats of varnish. The supports may be made of baked wood, mortised in the stand. Usually in plate machines this is little attended to, as the pads are often fixed to them, and they provide an imperfect connection to earth through the wood, but in this case only one electricity can be utilized, while by carefully insulating the rubbers we can use either; therefore if wood is used it should be made as non-conducting as possible, and the holes through which the axis is to work may be bushed with pieces of stout glass tube, the bearings being in loose pieces of wood screwed to the sides of the supporting frame; an ordinary winch handle gives the motion, that part of it which is grasped by the hand being a stout glass tube free to revolve over the handle.

IV. *The Circuit of Polarization.*—This, starting from the two faces of the rubbers and electric, is carried by the motion which thus produces the "separation" under the points of the prime conductor, then, crossing the narrow stratum of air in the form of small sparks or a constant luminosity, to the surface of the conductor; thence across the dielectric, the air of the room, to the walls, where it meets the corresponding action which, starting from the rubbers through the earth chain or connections, such as the table, polarizes in the opposite direction the surface of the walls. In charging a Leyden jar or other apparatus, part or all of the action is concentrated there, the two coatings forming the circuit with the material of the jar between them instead of the air.

V. *The Prime Conductor.*—This is the reservoir of force; on its size depends the nature and length of the spark. It usually consists of a large brass tube, and is a somewhat elaborate and expensive affair. This is by no means necessary when we rightly understand its objects; all that is really essential to it is the collecting portion; this is simply a coarse comb or a row of metal points fixed in a rod, and it is well to inclose this in a wooden shield, casing all except the points. The rod is connected to the prime conductor, which may be brass tubing as usual or of wood covered with tinfoil or Dutch metal. It must be carefully insulated or the power will be wasted; its surface must be smooth and brightly polished, and its form must present no sharp edges; all its outlines must be curves as large as possible, and where holes are provided for the insertion of conductors or apparatus, the openings should not be mere holes or tubes, but trumpet-shaped and formed into a curve.

The prime conductor need not be a part of the machine itself; the collecting comb may be connected to a separate collector. Dr. Winter of Vienna has devised a peculiar addition to the machine; it consists of a ring of iron rod a foot or so in diameter, mounted on a brass stem which may be inserted into a hole in the prime conductor, which in his instruments is simply a ball: the wire ring is inclosed in a ring of wood made in halves and cemented together and polished. It is stated that a machine giving 7-inch sparks gave 20-inch sparks when this was added.

47. It may be as well to mention here, that though brass chains are very commonly employed for connections, they are very bad for the purpose, for they are full of breaks and points; and if the machine to which they are connected is worked in the dark, a constant stream of fire will be seen passing from them; it is much better to use wire cord, such as is made for sash lines or hanging pictures, and to slip even this within a small caoutchouc tube; chains may be used to connect the rubbers to "earth" or surrounding objects, as there is little tendency to escape unless brought near the prime conductor or plate.

48. **Amalgam** is necessary to develop electricity freely, but its mode of action is not well ascertained; there are various formulæ given, but it is uncertain if any one has a special advantage.

Some of them are as follows:—

Zinc	5	11	2
Tin	3	24	1
Mercury	9	65	6

The best process of making is to melt the tin and zinc together in a porcelain crucible over a Bunsen's burner, then stir them well together till they are just about to solidify, when the mercury should be added, worked in, and the whole transferred to a small mortar made warm enough to soften the amalgam while it is well worked together, after which a portion of hard tallow not quite equal in bulk to the amalgam is to be worked in.

49. The foregoing principles being understood, those who wish to construct instruments for themselves may easily devise arrangements to suit their means. Very simple materials may be used, thus insulating supports or handles may be made from ordinary phials, the object to be supported being cemented into the neck with a mixture of about equal bulks of powdered resin and well-dried Bath brick melted together with a very little boiled oil.

As the working of machines is so greatly affected by damp, they may with advantage be built up within a closed box lined with ebonite instead of upon a frame, the axis passing through a stuffing box so as to exclude the external air, while the interior might be kept dry by means of a drawer containing lumps of fused chloride of calcium; in this case one side of the case might be made a condenser replacing the usual conductors.

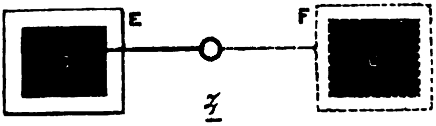
Friction machines are however going out of use, because of their defects, and the fatigue involved in working them. Induction machines produce equal effects with only a fraction of the exertion.

50. **Induction Machines.**—The second great division of electrical machines is based upon the principle of the electrophorus; there is not a constant friction, but a small charge is given to a piece of ebonite, and a revolving disc plays the part of the cover, taking a succession of charges, and transferring them to a condenser or conductor which in turn reacts upon the original charge and gradually raises it to a high tension. In these instruments, although there is no direct friction, there

is set up a resistance to motion by these electrical actions, which acts the part of friction and transforms the mechanical energy of the motion into electrical energy with all its effects.

The original of all the various forms was Varley's multiplier, in which was, for the first time, applied the principle of "accumulation," which, applied also by Mr. Varley to the magneto-electric machine, is the foundation of the powerful generators of current electricity now in use. In the generators both of static and dynamic electricity, the principle is that a small initial charge can be used to convert mechanical energy into electrical energy, and to develop a high force. The principle may be understood by means of Fig. 14. E F are

FIG. 14.

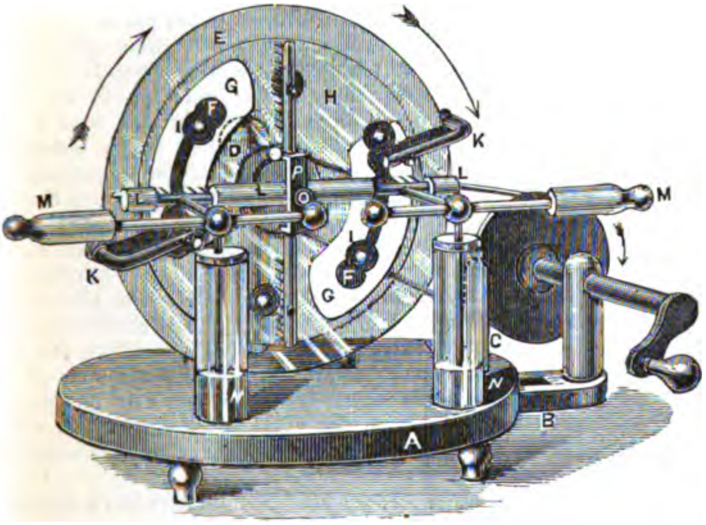


plates of metal (which in the instrument were arranged in a row) in front of which the plate C (which represents the electrophorus cover in principle) can rotate. The plate is carried on an insulating arm, but with appliances by which at proper intervals it can be connected to so-called "earth," really a zero point indicated on the diagram by z to which C can be connected at the required moments, as also can other plates similar to E, F; a small charge, such as may be obtained by rubbing a plate of ebonite, is put upon E, which represents the electrophorus face, which we will consider as being in a + condition. C being connected to z, which represents the back or sole of the electrophorus at this stage, of course takes a − charge equal to the + on E. C is now moved, breaking connection with z, and carries its − charge over to F, with which it makes momentary contact; contact with z following, a + charge is at once induced on C, which it in like manner carries on and adds to that on E. In the actual instrument, of course, the charges which are induced upon C involve a corresponding opposite quantity transferred, by means of a temporary connection to z, to another set of plates similar to E F, in which the same series of operations are carried on. At length the charge rises to the full "potential" of which the insulation of the instrument admits, and then the electricity overflows into the external circuit.

51. These principles have been applied to a variety of machines constructed by Holz, Töpler, and others, and a very small form is employed in the elaborate electrometers now made on the quadrant principle of Sir W. Thomson, § 64, for the purpose of maintaining the electric charge upon the moving system. These machines, especially the Holz, will be found fully described in most of the text-books of electricity and of physics, so that I will not occupy space with them, but give a full description of the latest and probably the most satisfactory form, which is easily made by any one with moderate skill.

52. **The Voss Machine.**—The base board A, Fig. 15, has upon its lower side a groove formed by two strips of wood fitted longitudinally; in this slides a bar of wood B, carrying an upright stem of wood, through the upper part of which there crosses a brass tube, the ends of which contain stout rings of brass to form bearings for an iron axle on the further end of which is clamped a large driving wheel, while the other is fitted with a handle for working the machine. The tension of the driving cord is controlled by sliding the bar B, which

Fig. 15.



carries the whole system, in its groove, and fixing it by means of C; this, which cannot be clearly seen in the drawing, as it is hidden by other parts, is a handle of wood, carrying a screw which passes through a longitudinal slot in B, and into a nut upon a strip of iron fixed across the groove, so that when the screw is tightened up it clamps the sliding bar B against the base.

On the further part of the base there is a strong wood pillar D, the end of which is turned down to fit a hole in the base to which it is screwed from the bottom when truly adjusted. From this pillar there projects the axis which carries the working parts; this is formed conically where the moving parts work on it and its end is reduced to receive the various fittings. A little above this axle there is also a rod of ebonite projecting from D, with a notch close to its end to carry the fixed plate, which is also supported by two notched pegs of ebonite fixed in the base board, only one of which is seen in the figure.

The fixed disc E (say 12½ inches in diameter) has a central opening of 3 inches diameter. Let us imagine a circle drawn on this of 7½ inches diameter, divided into six equal parts; on two opposite pairs of these points are fixed 1-inch discs of tinfoil, shown F F on each side of the plate, connected together by a strip of foil. The intermediate points are unoccupied in this fixed plate, and it is not unlikely that the working would be improved by dividing it, and leaving an open space between the two parts in the vertical line. G G are segmental shields of paper pasted over the pairs of foil, and projecting beyond them, half of one division, in the direction of the motion: strips of foil also connect opposite discs of the two pairs to brass clamps, which are fixed to the edge of the plate and project beyond it, and have holes in them to carry the fittings K K. The plate E is to be placed upon its supports, with the foils and shields at the back. Its whole surface (except upon the shields which are required to act as partial conductors) is carefully varnished, as is also the moving plate, in order to prevent deposit of moisture; the glass also must be thin, such as window-glass, but perfectly flat, and of suitable quality, or other materials such as ebonite or vulcanized fibre may be substituted.

The moving disc H (say 10¼ inches in diameter) has a central hole for mounting on its axis, and should be divided exactly as the other into six equidistant points, to be fitted with inch discs of foil, *i i*, upon which are fixed small metal buttons: these are firmly fixed to the glass disc through small holes in the foil, by means of marine glue or other cement, but must make metallic contact with the foil; in rotating, these discs exactly face those of the fixed system. The plate is mounted with its plain side facing the other, and as near to it as is manageable (say one-eighth of an inch apart), so that the two glasses and this air-space constitute the inductive circuit between the conducting foils just as in Leyden jars or condensers, which they, in fact, constitute. The plate is now to be mounted on its hub, which is a brass tube fitted internally with a brass bearing at each end, drilled to fit the conical axis. On its further end is fixed an ebonite driving pulley, and on its front end a flanged collar of ebonite to fit the hole in the plate, and a nut of ebonite to screw on it and so firmly grip the plate, and effect its rotation.

The moving system is now passed on to the axis through the opening in the fixed plate, and secured in position by a broad brass nut screwed on the axis, and upon the face of which two steel pins are fixed in the horizontal line, to carry the remaining parts.

L L is the collecting system, composed of a stout rod of ebonite, slipped upon the projecting axis and the two pins just mentioned, which hold it firmly. At each end of the rod are brass T-pieces, fitted with projecting pins nearly touching the glass plate and the metal buttons. At the ends of these combs are blocks of ebonite with projecting pins of ebonite, which reach to the fixed plate and keep it steady and at the proper distance. The other branch of the T-piece terminates in a ball, drilled to receive a sliding-rod for the conductor, fitted with ebonite handle M at one end and a movable ball at the other.

Leyden jars N N, with foil on their lower parts, support the end of the collecting system by their brass terminal rods entering holes in the brass knobs above them: these wires are connected to the inner coatings by wire brushes on their ends. The outer coatings are connected together by means of metal saucers in which the jars stand, and which are screwed on the base and connected together by a wire beneath. It would be better to thoroughly insulate them and provide a shifting means of connection, or ebonite pillars might replace the jars, which could then be suspended from the collecting rods as in the Holz machine, or a single jar have its coatings connected to the two collectors, so as to be able to vary the conditions. A second pair of combs screwed to a brass frame P also fits on the projecting axis, and is held in place by an ebonite ball screwed on the end of the axis; these combs have in their middle a brush of fine wire which just touches the buttons of the disc, and the function of this part is to make contact between and discharge the several parts of the disc of any residual electricity not taken up by the collecting combs: it represents z in Fig. 14. Its working position is not vertical, as shown, but just over the end of the paper shield; and the fixed plate itself, though working in different positions, is probably best arranged with its discs equally above and below the collectors.

K K are brushes carried upon bent arms screwed to the clamps on the fixed plates connected by strips of foil to the adjoining pairs of discs: the brushes are so adjusted that they just touch the buttons as they pass under them, so as to connect together the discs of the fixed and moving plates which are exactly opposite each other.

The special property of this machine is that it requires no initial charge to be given it, because, as with magnetized iron, there always remains some residual charge about it which can be worked up. It is also said to be unaffected by damp air, but I have not found this to be the case; like all other machines, it should be worked in a warm and dry room.

53. An examination of the machine while working in the dark is both interesting and instructive. It will be seen that an aigrette, or brush discharge, occurs into surrounding space at one of the appliances K, while at the other there is a small star of violet light indicating the + and − charges of what we may properly call the "field inductive system," for it plays the part of the field magnets in dynamo-machines. If a metal point, held in the hand, approaches either of these parts, the instrument ceases to act, and if a momentary circuit is closed between them, the direction of the circuit is apt to be reversed—a consequence which appears also to result from making the paper shields too long.

A line of fire will be seen tending to the points of one of the collecting combs, and a similar effect is seen at the points of the secondary comb, Fig. 15, and here is manifested the relation between inductive circuits, which is the same in principle as in the case of currents and conductive circuits.

54. We have, in fact, two derived inductive circuits—that of the field system along the surface of the plates, and the external path between the two conductors, and these two divide at the collecting combs. If we bring the conductor knobs close together, we reduce the external inductive resistance; the greater part of the available electricity takes that road, and may be seen streaming into the collector system. But, if we open the space so as to get a long spark, an increasing change takes place in the ratio of the two resistances, and increasing action is seen to occur at the zero comb,

while that at the collecting system is reduced. The long spark has, therefore, less electric energy in it than the shorter.

55. The spark appears like a continuous stream of lightning; but this is an illusion due to "persistence of vision." It is really a succession of sparks, each enduring probably $\frac{1}{20000}$th of a second, but following each other at intervals less than one-sixth of a second, the intervals being indicated by the snap at each discharge. When a wheel rotates rapidly all its spokes vanish into a sort of blur, but such a wheel is seen by a lightning-flash as though it were at rest. The discs on the plate of the Voss disappear in this manner; but in the dark they are seen as if at rest, or even as though moving backwards. We have, in fact, the conditions of the rotating vacuum tube worked by an induction coil, which presents the appearance of a stationary cross or star; or may have an appearance of reverse motion, according to the relation between the speed of rotation and the action of the break.

56. If we place the balls of the conductors so far apart that sparks will barely pass, and then tie a piece of soft thread across the space, sparks pass freely, notwithstanding that the thread is a partial conductor; because, the resistance being reduced, the current is drawn over to the external circuit, and the charge on the field can be raised to a higher potential. This thread will now give some valuable instruction. Approach the balls so that the thread hangs quite loosely and takes up a partial charge, + at one half, and − at the other; the same, therefore, as the balls close to it. It will be seen at once that, though charged alike, there is no repulsion between the balls and thread adjoining, but a small attraction. There is, however, a strong attraction for the other end of the thread, and it is drawn over as tightly as possible in opposite directions, leaving a loop which instantly turns up over the thread, and stands balanced between the attractions acting on its two sides. Sometimes it will manifest a preference for the positive ball and remain on that side. If the thread is cut in the middle, its ends rise and meet as soon as the machine is worked, and will cling together for a long while; if forcibly separated they will fly over to the adjoining Leyden jars, the outsides of which are in opposite polar conditions to the balls near them.

57. By taking off one of the balls of the conductor, leaving a point, the star and brush discharge is produced, and illustrates the difference between the + and − actions of electricity, according to which ball is removed; when the brush is produced at the ball, there is a hissing sound which is not produced

when the + discharge occurs at the point without developing the brush discharge.

58. A metallic-sponge benzoline-lamp placed between the balls gives remarkable effects. On working the machine with the lamp insulated, a slight tendency of the flame to one pole is observed, with an evident blowing action from the other; when the lamp is connected to either pole, the flame tends to the other. But this is masked by a very much stronger action which occurs when the lamp is made positive; then the flame is driven in a bubbling cascade down the wick stem, burns much more strongly, as though the benzoline were rapidly drawn up; and if the speed is great, the lamp may even be extinguished by this action.

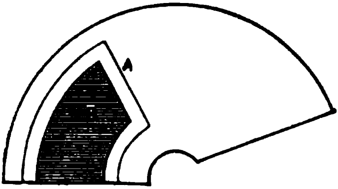
59. I have found some curious effects when passing the discharge through a sensitive galvanometer; if connected direct from the collectors, of course the potential cannot be raised highly, because the outer circuit carries it off; in this case the deflection increases with the speed of rotation: interposed resistance up to 10,000 ohms produces, of course, no effect, as this has no appreciable ratio to the air-space between the glass and combs. A resistance of many megohms would be requisite. If connected from one collector to a third separate ball from which the action occurs, I found a deflection of 50° (Ampere ·00004) with the balls in contact; on separating a ¼ inch so that sparks crossed, the deflection fell instantly to (Ampere ·000005) 10°, showing that, notwithstanding the greatly increased potential or force, there was less quantity generated. As the balls separated, the deflection increased till, at the distance at which sparks ceased, and only a hissing discharge was produced, the deflection rose to 45°, although under these conditions the galvanometer was only a derived circuit, taking, probably, less than one-half of the current generated.

According to similar experiments made in Germany with a Holz machine, the electromotive force was about 53,000 volts and constant for all speeds of rotation; this latter seems doubtful. It was also found that the resistance was nearly inversely proportional to the speed of rotation, being 2810 megohms at 120 per minute, and 646 megohms at 450 revolutions; this also seems doubtful, and as the result is the same as that I have stated above, that the current is nearly proportional to rate of revolution (as is the case with magneto-electric machines), it seems probable that the effects of electromotive force and resistance are not very easily ascertained or measured in these machines.

60. The machine as shown Fig. 15, can easily be converted

into a Holz machine, if desired, by changing the plates: a plain disc of glass is used for the moving plate: the fixed plate can be constructed of a disc, cut for convenience of making up into two pieces as shown Fig. 16. Lay a strip of wire gauze on the glass on the lower edge of B, projecting so far that it can be doubled over the edge of the glass and nearly reach to the moving plate: over this fix the strip of tinfoil B, and then the paper A, varnishing all the exposed glass. These two segments can be suitably supported, or small strips may be laid between them at the opposite edges, and other strips cemented over these so as to build the disc up again, when it can be supported exactly as the fixed disc is in Fig. 15. The second pair of combs for short circuiting will not be required.

FIG. 16.



To work the Holz the two conductors are brought in contact; a piece of ebonite is rubbed and laid on one of the paper armatures. The disc is then rotated and the arms gradually separated. If the motion is arrested, or if the arms are separated beyond the distance at which sparks can pass, the machine loses its charge and the process must be recommenced.

In constructing any of the different machines, a strip of wire gauze forms a very effective comb, easily made. Brass rods, balls, &c., may generally be substituted by wood covered neatly with tinfoil or gold leaf, and in many cases, sound wood, very carefully baked and then boiled in melted paraffin, may replace ebonite.

61. ELECTROMETERS.—The instruments described § 24 are simply indicators of the presence of electric excitement; they do not distinguish its character as + or −, and only give a very rough indication as to its degree; but to get accurate information, something more exact is needed, and it is desirable to be acquainted with these before proceeding to study the actions of electricity.

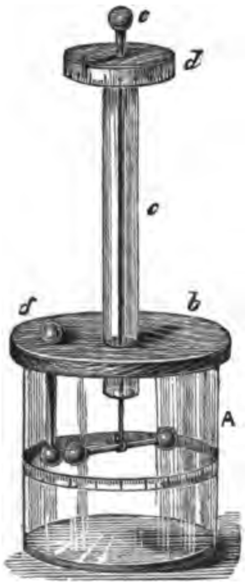
Henley's Quadrant is scarcely more than an electroscope, but is easily made, and useful for indicating high charges, as for attaching to the conductor of a machine at work. It is simply a wire, carrying a plate of ivory (card, baked and paraffined, will answer) upon which a quarter circle of degrees is drawn; a pith ball hangs by a fine thread from the centre of the circle.

The wire should be curved and fitted with a ball, against which the movable one will rest, with its thread cutting the vertical line of the quadrant. The ball is driven out to an extent dependent on its weight and the potential of the charge in ratio of the tangent of the angle.

Harris's is a more delicate modification, in which a wire is attached to the centre of a circle carried by the conducting wire, in such a way as to arrange a ball at each of its ends on opposite sides of the zero line; the moving system is a wire or a straw with a ball at each end, and is pivoted on a centre pin, so that it can rotate; in this case there is not the whole weight of the one ball to raise, but only so much as the lower part exceeds the upper in weight.

62. COULOMB'S TORSION ELECTROMETER.—This, Fig. 17, was the first good instrument known for measuring attraction and repulsion, and by its means their laws were ascertained. A is a glass cylinder, round which is fixed a circle graduated to degrees; *b* is a cover of baked wood or ebonite, in which is cemented *c*, a glass tube terminating in a cover *d*, also graduated; *e* is a ball fitted with a pointer, and from it is suspended by a silk fibre or very fine wire, a stem of shellac ending in a ball which is gilt; *f* is a ball and stem of insulating material terminating in a gilt ball of exactly the same size as the one on the suspended needle; this passes through a hole in the cover, large enough to allow it to pass without contact.

FIG. 17.



The mode of using this instrument is to charge the ball on *f* from the body whose condition is to be examined; when inserted into its place it touches the other ball, divides its charge equally with it, and then repels it. The force of this repulsion is measured by the torsion of the suspending fibre, for any force producing torsion is proportional to the angle, or quantity of torsion. To ascertain this angle the balls are so arranged, that the movable one is opposite 0, on the scale of degrees, as also is the pointer on the upper scale; after repulsion the ball has to be brought to a fixed distance by twisting the fibre. Suppose the angle of repulsion be 36°, and it is required to reduce it to 18°, and that the upper pointer has to traverse 126° to effect this, 126 + 18 = 144° is the angle of torsion, and gives the measure of the charge in the terms of the particular instrument. To measure attraction, a stem of insulating material has to be passed through the cover, after the ball on the needle has been moved back, so that this rests against it when attracted, and then the force of torsion required to increase the distance is ascertained as before.

63. A precisely similar instrument is employed in measuring the attractions and repulsions of magnets; for this purpose a magnet is suspended in a stirrup of paper attached to the suspending fibre or wire in place of the stick and balls shown, and a magnetic pole presented in place of the charged ball.

64. **Balance Electrometer.**—Sir W. Harris devised an apparatus which is an ordinary balance, one of the pans of which is a disc, below which is an insulated disc of the same size, which is charged from the prime conductor, and the attractive force at varying distances may be thus weighed.

Sir W. Thomson has modified this by adding a large guard ring outside the moving plate, so as to do away with the effect of the unequal distribution at the edges. The moving disc is attached to a balance arm by metal wires, so that it plays in the middle of the large fixed guard ring, which is also electrically connected to the same source, and takes the same charge: underneath is a plate as large as the ring which is connected to the opposing conductor either direct, or through the "earth" connection.

Measurement is obtained either by actually weighing the attraction, or by altering the height of the lower plate, so as to vary the distance: the position of equilibrium is with the lowest face of the disc exactly level with that of the ring.

A more elaborate and accurate instrument is Sir W. Thomson's quadrant electrometer for very delicate measurements, which will be described in the chapter on Electromotive Force.

65. **Bohnenberger's Electroscope** has the advantage of indicating the + or – nature of the charge: it consists of two conductors maintained at equal opposite polarities. Between them hangs a gold leaf, or a wire with a gilt pith ball, suspended to a knob from which it can be charged with the electricity to be examined, and which causes it to be attracted towards the oppositely charged conductor: a scale can be placed behind so as to read the angle as in other instruments.

In the original instrument the charge of the two conductors was maintained by means of a "dry pile," but any constant source, such as a series of small galvanic cells, can be used.

66. **Dry Piles.**—The name is erroneous, because they are to all intents galvanic batteries of enormous resistance, developing high potential, and not meant to generate a current: but they work purely by chemical action due to the moisture contained in them.

Various materials may be used: zinc-foil, paper, and copper-foil pasted together will serve, but the best is composed of zinc or tinfoil pasted to paper, the other side of which is rubbed with finely powdered oxide of manganese; it is said that honey is better than paste; after drying moderately, a number of such sheets are laid in regular order over each other, and discs punched out of them, say 1 inch in diameter; these are packed, to the number of several hundred pairs, in a dry glass tube fitted with brass ends tightly fixed over the discs. Such a rod resembles a magnet in having polar ends, and would manifest the same lines of force as the bar magnet does.

Such piles have a permanent charge, + at one end, − at the other, and will act upon electroscopes; or if formed like a horse-shoe magnet, with a ball or gold leaf suspended between the poles, will maintain a steady vibration of this, ringing a bell, &c., for years.

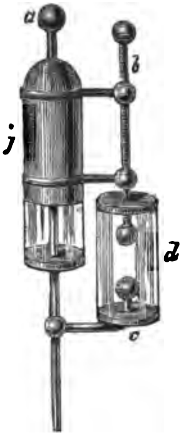
But such a use of them eventually destroys their power: it is developing a current from them, which needs a supply of energy; they might however prove useful for some experimental work in which a prolonged minute current is desired, as they would require no attention. But their proper use is to maintain a "field of force" between their poles; or to serve as an electric wand or touchstone.

67. **The Unit Jar.**—This is a useful measurer of the "quantity" of electricity employed in producing a "charge"; it acts in much the same manner as a pint measure does with liquids, or would with gases if fitted with a gauge for their pressure: this is just what the unit jar, Fig. 18, has. *j* is a small Leyden jar with a covered surface of say 6 inches; the inside is connected to a metallic stem which can either be inserted in the prime conductor or mounted on an insulating stand; to it is also connected a stem *c* terminating in a ball; the outer coating has a ball *a* which is connected to the jar or battery to be charged, it is also provided with two metal rings which carry a screw stem *b* ending in balls; by it the distance separating the discharging balls of the two coatings is regulated, and consequently the potential to which the jar can be charged; *d* is an advantageous addition to the ordinary form, to prevent

the irregularity attendant on the moisture of the air: it is simply a cylinder of glass closed at the two ends with india-rubber through which the stems of the two balls pass; a lump of chloride of calcium placed inside will keep the air dry.

As soon as the charge rises to the potential corresponding to the distance separating the two balls, a spark passes and discharges the unit jar without affecting the battery or large condenser, and by counting the number of sparks which thus pass during the process of charging, the amount it has received is pretty accurately measured, because each spark implies a constant quantity and potential. Of course, a unit of this kind can also be constructed of paper, &c., and be thus made of exactly the same specific quality as the condenser with which it is to be worked.

FIG. 18.



68. THE LEYDEN JAR.—This instrument, accidentally invented without any knowledge of the principles it is dependent on, is a receiver or reservoir of electricity: it was originally considered, and is still often described as though it were a bottle to be filled with one electricity, and provided the true explanation be well understood, some advantage may be obtained from this view. The jar has "capacity" as a bottle has for a gas, and as with a gas the "quantity" which can be stored in it is proportional to the pressure and also reacts in the form of pressure or tendency to escape in proportion to the quantity contained. But the analogy is not quite perfect as to this reaction or pressure: in the case of a gas, quantity and pressure are proportionate; in the case of electricity the relation is between quantity and "potential," which is related to the square root of pressure. The explanation of the theory of the Leyden jar will be found under the several heads; it really involves the whole question of the inductive circuit and the nature of static electricity. See §§ 91–94.

The Leyden jar is simply a "condenser." The bottle form was accidentally used in an experiment as to the action of electricity on water: it is, however, the form best suited to electricity at high potential, because its closed form gives most resistance to discharge. It consists of a glass or ebonite jar, covered inside and out with tinfoil, except at the upper part, where the surface should be varnished; it should have a cover of insulating material in the centre of which a brass knob forms the conductor, connected to the inner coating by a wire terminating in a soft wire brush or piece of metal chain. Sheets of glass or ebonite coated on both sides may be used mounted in a frame, but will not bear so high a strain as jars. Either form may be combined (like galvanic batteries) for "quantity" as one, in multiple arc, or for "force" in series. Also, to obtain either condition from the other, they may be charged from a low power source as one, and then connected for discharge in series, or they may be charged in series, from a powerful source, and discharged as one for quantity. This used to be called "charging in cascade."

The same remarks apply to glass for this purpose as for electrical machines § 49, but the reasons for this will be found § 95 on specific inductive capacity, and the conditions governing the actions of charge, discharge, &c., are explained §§ 84–91.

69. CONDENSERS.—These are used for receiving charges of a low potential and are of much value in cable telegraphy, and with induction coils; they will not bear very high charges, but are most conveniently described here, because they are, in principle, pure Leyden jars. They consist of sheets of some dielectric coated with tinfoil connected alternately to the + and − terminals. Mica is found to be one of the best materials, but for many purposes paraffined paper will answer.

The best mode of construction is to cut up the tinfoil into sheets of the size desired, and to make of them two piles like the leaves of a book, the one which will represent the outer coating of a jar containing one sheet more than the other, which represents the inner coating: upon the extreme end of each of these piles place a tinned wire or strip of metal, and by means of a soldering iron run all the edges together so as to make a perfect metallic connection. The foil should be well baked and warmed when about to be used, to drive off all moisture from the surfaces of the metal, and it is well to rub each leaf as it is laid down with a dry warm cloth. Cut sheets of paper large enough to allow a margin of at least an inch, round three sides of the foil. The paper should be thin, not highly glazed, and should show no acid reaction by reddening when moistened with a neutral solution of litmus; it should be baked thoroughly dry, placed in a vessel of paraffin kept well over its melting-point, and then drained sheet by sheet as smoothly as possible. A well-baked piece of wood of the same size or larger than the paper is laid upon a table, its face soaked with paraffin and a sheet or two of the paper laid upon it; upon this is laid the "outer" pile of foil with its soldered end somewhat projecting, and all its leaves turned back except the lowest one which is to be rubbed smoothly out on the paper; lay over this two sheets of the paper, and on the top of this the other book of foil, so placed that it lies exactly over the first sheet excepting for the margins at the opposite ends; turn back, as with the other, all its leaves except the first, and upon this place two sheets of paper; continue this process, laying back upon the paper, sheets of foil from the books alternately, and between each foil two sheets of paper; when the whole are in place, cover with two or three sheets of paper and a board like the first: the whole should then be compressed by clamps or by screws passing through the two boards, and warmed up to the melting point of paraffin, increasing the pressure to drive out all excess. The first board should be provided with a binding-screw at each end, and the wire of the corresponding set of foils soldered to it. But the terminals are usually composed of brass blocks on the upper part of a case containing the condenser, fitted with connections for use and so placed that when not in action, the condenser can be short-circuited to secure complete discharge. See § 94, *i.*

Fig. 19.

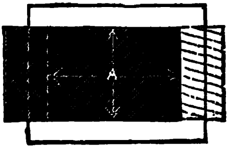


Fig. 19 will explain the process of construction. It is desirable to keep a delicate galvanometer and a battery in circuit through the screws, so that if by any accident or defect a contact or circuit is completed during the process, the galvanometer will at once show it. But it must not be forgotten that some current will always pass, because melted paraffin has considerable conductivity, as also has shellac varnish until perfectly dry.

70. Charge and Induction.—We can produce two effects upon a gold leaf electrometer or a pair of suspended pith-balls. If we rub a piece of ebonite, and then approach it to the knob from which the leaves or balls are suspended, they gradually move apart; if the approach is continued till contact is made, or if we connect the knob to the conductor of a machine, the leaves remain apart when the contact is broken and the electrometer is left isolated. The leaves are then said to be electrified or in a condition of *charge.* The same condition is produced in any body which has been thus placed in a direct circuit from an electric source, so complete as to effect what we may call a *transfer of electricity* to it. The state of affairs produced is such as would arise from the deposit upon the body

of some agent, and this apparent effect was the origin of the fluid theories of electricity, and of all the supposed laws which are said to govern the distribution of electricity.

If we approach the ebonite to the knob, but not so as to touch, the leaves diverge, but on removal of the ebonite they fall together again, and show no trace of electricity upon them: while diverging they had electricity upon them, but this temporary charge is said to be an *induced charge*.

Further, if the leaves or balls are touched while thus diverged under the inducing influence, then upon removal of the inductor they will continue divergent. This is said to be due to an *induced charge* which proves to be of the opposite nature to that of the inductor.

The divergence of the leaves or balls is said to be due to a repulsive force, due to the self-repulsive nature of electricities of the same name, with which each is charged. These three ideas, *Charge*, *Induction*, *Force*, when clearly worked out, explain the whole of the static actions of electricity.

71. LAWS OF ATTRACTION AND REPULSION.—It has been found that both these effects obey the same laws, and are alike affected by distance of the surfaces and quantity of charge.

Distance.—Taking the same figures as in § 62 where 18° required 144 of torsion force, if the balls be approached to 9° the upper point will move through 567°, and this + 9° is a force of 576. We have thus three distances to compare, 36°, 18°, 9°, which are in the ratios of 1, $\frac{1}{2}$, $\frac{1}{4}$; but the corresponding forces are 36, 144, 576, the ratios of which are 1, 4, 16. Hence we have law (6). The repulsive force between two bodies similarly electrified varies *inversely as the square of the distance.*

Quantity.—If the instrument be now charged as before and the force measured at a fixed distance, and if the fixed ball be now removed and discharged, when replaced it will again divide the charge, which will be only one-half of what it was before, but it will be found the *force* is only one-quarter of the former force: if the process be repeated the quantity or charge will be reduced to one-quarter and the *force* to one-sixteenth. Hence law (7). At equal distances, the force between two similarly electrified bodies varies *as the product of the quantities of the charges.*

As the quantity is in most cases equal and opposite, the effect is that the force is as the square of the quantity.

Combining the two the force is $\frac{Q \times Q}{D^2}$.

Though these are called laws, they are only the phenomena of a fixed state of facts: they are true as to a particular condition, or when the whole of a charge is concerned; their true relations can only be understood when the nature of the "inductive circuit" is realized, and account taken of the variations produced when that circuit divides into several branches.

72. QUANTITY.—It is important to obtain definite conceptions of the various terms to be employed, and this one, apparently so simple, is one of the most difficult to define, because there is and can be *no quantity of static electricity.* In currents we have a definite measure for quantity in the relation of electricity to matter in the form of chemical action: there is nothing analogous to this in static electricity. The fact is that static electricity deals only with force and energy: there is no static "*quantity*" existent, only an *attraction*; so that while we speak of static quantity we can only define it in terms of force: it means the force acting within an area or space. As will be seen when the system of units is studied, there are two systems of measurement; upon the electrostatic system, the unit of quantity is *that which at one unit of distance repels an equal similar quantity with unit force.* In the centimetre-gramme-second or C.G.S. system, unit quantity is that which at the distance of 1 centimetre exerts a force of one dyne.

The most satisfactory conception of this is, *a line of force,* which we may materialize as a strained spring of defined strength: but for purposes of calculation and experiment the conception of a fluid called electricity (though erroneous and misleading in many other cases) answers the requirements. That is of course how the fluid hypothesis came to be devised when these phenomena, to which it fits, were all that was known of electricity.

The unit of quantity employed in all practical operations is one of the electro-magnetic system, the *coulomb*, which is the quantity corresponding to the unit of current, the ampere, and properly belongs to dynamic electricity. But this is too large for use, and the real unit employed is one-millionth of it, that which can be contained in a condenser of 1 microfarad capacity under the potential of 1 volt.

These more exact ideas and measures will be examined hereafter. At present the simplest conception of quantity will best serve the purpose of the student. Perhaps the simplest and best idea is given by means of the unit jar § 67. Such a quantity as will be contained and delivered as a spark, in a jar of a known size charged under a known potential, i. e. with its sparking balls adjusted to a fixed distance.

Quantity or charge varies in the ratio of potential, in a fixed receiver or conductor: electrometers only measure quantity by means of this relation; their action is due directly to the potential, and attractions in the field.

73. DENSITY.—This term represents the "quantity per unit area," that is to say, the number of lines of force or units of electricity concentrated upon a unit surface. Density is equal at all parts of a sphere at a great distance from surrounding bodies, or surrounded by a concentric sphere: it is equal also at all parts of large plates opposed to each other at a small distance. Where the distance of surfaces is not equal at all parts, the density is greater as the distance between the opposed surfaces is less, that is to say, the density is inversely as the inductive resistance. As a consequence it is greatest at any projecting points or edges: this is due to two causes: (1) So many lines of force can form from any surface as can pass from it to the opposed surfaces: from a sphere this is alike at all parts; but a projecting cone will have its capacity for lines of force increase as its length increases, while at the point it will be a centre for the whole opposing area except that of the cone behind it. (2) The law of inverse squares, owing to which the force or attractions, § 71, on each part of the surface increase as the square of the reduction of distance due to the projection. It is usual in text-books, to give pictures of spheres, ellipses, and so on, with dotted lines surrounding them to illustrate the density, or as some say the depth of the stratum of electricity retained at the various parts. These are misleading, because they ignore the fundamental fact that the distribution is not a matter of the form of the charged body, but one entirely dependent upon the position of the equal opposite charge, which is inseparable from it. Some books endeavour to counteract this by saying that the distribution shown is correct only when the charged bodies are at a great distance from all other surfaces. It appears better for the student to look at the general truths involved, that is, to examine the dielectric to which the surfaces are electrodes, and the length of the lines of force, rather than a mere isolated example, because that happened to be what presented itself to the early observers.

In the case of two concentric spheres oppositely charged it is evident the densities must be inversely as the squares of the two radii, because this is the ratio of areas or surfaces of the spheres. Now in the case of a single charged sphere in the middle of a room, we may regard the surrounding walls as a sphere, and if the radius of the ball is 1 inch and that of the walls 6 feet (12-foot room) or 72 inches, it is evident that the density upon any part of the walls will be as $72^2 = 5184$ is to 1.

This is the reason that this opposing charge was so long undiscovered and is in ordinary cases inappreciable. See § 84.

When the density exceeds a degree varying with the nature of the material, the dielectric breaks down and discharge occurs; this maximum density for air is about 20 electrostatic units per square centimetre.

74. FORCE.—This is the fundamental expression in all mechanical operations for the capacity of producing acceleration: but in statics a force is measured as a *pressure* or a *pull.* In a vertical column of water, the pressure at any height is the measure of the force exerted at that point by gravitation. We have such a force in electricity, but it is not what is called "electromotive force," or potential. The force in electricity is expressed by the strain it sets up in a dielectric, and, by the attractions it exercises across the dielectric—that is to say by the attractions and repulsions—the motions it can cause in a body under its influence.

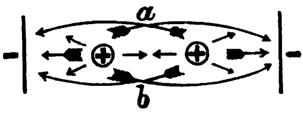
Attraction is the true evidence and action of the force: this is evident from the fact that the normal condition of electricity is with its equal opposite + and − facing, and in this state the full force is manifested as attraction, which measures the effort to unite, or to go a step further, the effort of the energy stored as electricity to pass into the form of heat.

Repulsion is an indirect action of attraction: nowhere in nature can there be found a *repulsive force;* there are repellent actions, which are simply transfers of motion, as when one billiard ball strikes another; or else they are actions of a field of force, as in the case of magnetism § 120. As there is always a second surface somewhere, charged with opposite electricity, the apparent repulsion is really an attraction towards that surface; as every charged surface is a boundary of a field of force, in which lines of directive energy exist, so any body free to move in the field moves in the direction of those lines.

Motion of any kind, whether to or from a surface, always means a reduction of the inductive resistance or a transfer of energy along the lines of force.

The action may be traced by Fig. 20. + + are two similarly charged surfaces, while − − are surrounding surfaces; the outer arrows show the direction of the forces from each + to each −, while the two small arrows show the neutralized state of the space inclosed by + and +, *a* and *b*.

FIG. 20.



Inasmuch as attraction varies (§ 71) as the square of the distance, it is evident that the pull in the direction shown by the long arrows must be greatly inferior to that of the short one to the nearest −; hence an *apparent* repulsion between + and +.

For purposes of calculation the mathematical system of treating such different actions as + and − forces, is of course convenient. So also, although it is not possible to have unequal quantities of electricity really related to each other, yet it is convenient to treat the different parts of a complicated surface as though each + and − charge were an isolated thing. That is to say, if we have a + charge = 5 and a − charge = 3 there is somewhere another − charge = 2; the true condition is that there exist two distinct inductive circuits 3 + −3 and 2 + −2 which are analogous to derived circuits in currents, but we may include the effect of the other circuit by calculating the actions as due to + 5 and − 3, and referring these actions to an artificial datum or centre.

In fact the force between naturally charged surfaces is as the square of the quantity upon one, Q^2 or as the product of quantity and potential, these varying alike. But the mathematical formula is $Q \times Q^1$ (the product of the two quantities be they + or −) in order to enable the different parts to be dealt with as though each were isolated.

Force varies as the square of the distance when regarded as exerted from a central point; this is in fact a necessary consequence of radiant action, because spheres vary in surface area as the square of their radii. But in flat plates properly guarded, as in the balance electrometer § 64, the attraction is as *the distance.* But though we have thus, *distance* simply in one case and *square of the distance* in the other, the same cause and law is operating as will be seen § 94. The flat plates are simply equivalent to parts of the surface of very large spheres, and the actual distance apart bearing no relation to the length of the radii, the difference of the squares of the two (theoretical distances) is practically undistinguishable from the distances themselves.

Hence, Force varies as square of Quantity.
" " square of difference of Potential.
" " inversely as square of distance from centre.

75. TENSION.—This term is so differently used as to cause much confusion, as may be seen from the following quotation from Gmelin's 'Handbook of Chemistry' (a curious name for a

work extending over many large volumes). "The tension of the unclosed circuit as determined by the electrometer increases directly as the number of pairs (Volta, &c.). It increases as the square of the number of pairs (Delezennes). In the unclosed circuit, it increases as the square of the number of pairs and in the closed circuit directly as the number, for the statical effects of a given quantity as shown in the open circuit by the electrometer are to the dynamical effects which the galvanometer exhibits in the closed circuit in the ratio of the square to the simple number (Peltier)."

The definition of tension as varying as the number of pairs in a battery, but manifested on the electrometer, is that of potential and electromotive force. All these can be expressed in volts.

When it is defined as varying as the square of the number of pairs, it cannot be expressed in volts: this is in fact the attraction or definition of force.

According to Fleeming Jenkin, "tension is measured in units of force per unit of area and is proportional to the square of the density on the element of surface."

The common sense of the word is connected to a pull or attraction; Clerk Maxwell defines it, "The tension of so many pounds or grains weight on the square foot exerted by the air or other dielectric medium, in the direction of the electromotive force." This means that tension is the "stress" on the dielectric, and in this sense it is occasionally used in these pages. In the first edition the word was used in the same sense as potential, and led to some confusion by the natural inference that potential or E M F in volts are analogous to stress (which is tension) instead of to its square root.

76. POTENTIAL.—This term is very generally employed in electrical works, because it sounds dignified; but it is very commonly misemployed and still more commonly misunderstood. It is used properly and advantageously in the more abstract investigations of "static electricity," but improperly in dynamic electricity in the place of electromotive force. The definitions usually given of it are quite unintelligible to the ordinary mind, and only cause confusion of thought. For instance the common definition, *The potential at any point is the work which must be spent upon a unit of positive electricity in bringing it up to that point from an infinite distance*, involves several false assumptions and inconceivable ideas. It is impossible to bring anything from an infinite distance; and it is impossible to bring unit positive electricity anywhere, irrespective of its negative counterpart, which the definition treats as non-existent. In a discussion upon this subject in the pages of the *Electrician*,

in which the author and several eminent electricians took part, Clerk-Maxwell said, "The theory of electro-statics is greatly simplified by the introduction of this new concept of potential." "As soon as we pass from electro-statics to other departments of electrical science we find that the concept of potential is no longer available, except when used in a restricted sense and under carefully defined conditions." "In other parts of electrical science we have to deal with electromotive force in cases where 'potential' and consequently 'potential difference' are words without meaning." The term was not employed in the first edition of this work, but "tension" was used in the same sense. Tension itself is employed in two senses by electricians, § 75, and as the use and meaning of potential is now better understood, and the word generally employed in electrical writings, it is used here now in its application to static conditions only, and I will endeavour to make its meaning clear.

Professor Baynes (in the discussion referred to) remarked that potential is the *square root of force*. See § 74.

Dr. O. Lodge defined the "potential of a point as the potential energy of unit electricity, if placed there."

Both these definitions are really embraced in the explanation attempted, of the relations of force and energy to electric current in the sections treating of Ohm's formulæ in the chapter on Current.

77. Potential has often been compared to pressure, as for instance to head of water: tension has an obvious analogy to the pull exerted by an attraction, or to the pressure of steam in a boiler. When the subject is fully examined, as it will be later on, it will be found that this is the true idea connected to the term. In fact this is the meaning hidden under the favourite definition given in § 76, for the "work expended upon unit electricity" in raising it to a given potential implies the same idea as the "work expended upon unit weight" in raising it to a given height. But none the less the expression is very erroneous and misleading; it would be erroneous to say that "gravitation effect *is* the work expended upon unit weight," though it would be correct to say that it is proportional, upon unit weight, to the work expended in raising it. So potential *is not the work*, but a general expression for such a stress as would be capable of doing that work on a limited mass, such as unit weight, or unit electricity.

It is very important that the student of Natural Science should not rest in mere words and formulæ, but should realize their meanings, and endeavour to attach a definite concrete conception to the words he uses. This is the reason why I have endeavoured, in these pages, to lay open the natural facts and principles which really underlie terms which in most books are presented as though they were themselves the facts, and, merely called for a short definition.

78. The ideas embodied in "potential" are not confined to electricity, though the use of the word is very nearly limited to this science. Later on it will be seen that the ideas belonging to it are most clearly worked out in connection with water in hydraulics, where we have conditions strongly resembling those of electricity, both as to the static stresses, and the laws of current and energy.

Potential is strictly comparable to the pressure exerted by a column of water upon its base, or to the potential energy possessed by a unit weight at the top of the column. That is, it is as head of water in hydraulics.

But it has to be considered as the cause of current, and measured by the momentum it can generate, and in this aspect it is comparable to the square root of the head of water or of potential energy.

79. Potential and electromotive force are different ways of regarding the same agency and are equal in value: but one refers to static strains, the other to motion produced. Potential relates to the *Inductive* Circuit. Electromotive force relates to the *Conductive* Circuit. Both are measured in volts, and both are equal at the same point.

80. The term potential is often employed in a very mystifying manner: for instance, it is said that all the parts of a metallic surface are at one potential, because if they were not so, current would flow along it. But this is reasoning in a vicious circle; the potential itself is defined as the power to set up the current. The parts of the surface are at one potential only in the artificial, mathematical, electrical sense; that is as related to an imaginary zero. But if a surface varies in its distance from its opposed surface, if for instance the two surfaces are inclined to each other, the attractive forces, therefore the potentials, the density will vary all along the surface: every part of it will have its own inductive circuit, with its own potential. The different parts of the one surface have no relation to each other in this aspect, any more than if they were cut up into a series of insulated parts. See §§ 91, 92.

It is also commonly stated that, in this artificial electricity the potential is the same at the end of a long point, as it is on the sphere to which the point may be connected: this is also a consequence of the definition and *because they are connected:* but the electromotive force, the tendency to discharge, the relation to the opposed surface are very different at the sphere and the point.

As this work deals only with the electricity which exists in nature, the term must never be understood in these pages as conveying any of these imaginations, but purely as the static analogue of Dynamic Electromotive Force.

81. Distribution of Electricity.—Most electrical works occupy many pages and numerous illustrations to show that *Static electricity is found and exists only on the surfaces of bodies.* Faraday made many beautiful experiments to show this, and to prove, among other things, that the force is to be found only on *external* surfaces. In fact, this is the sole meaning of the statement as made by the earlier electricians, who experimented purely with objects placed in an ordinary room, and considered only the actions observed on those objects: these old theories of charge by an isolated single electricity, were really destroyed as soon as it was found that electricity could be placed upon an *internal* surface. But electricians still cling to the old form of words when the meaning is entirely changed: and if some of my readers find that the newer explanation is several times repeated as the special occasions call for it, it should be understood that this is on account of its extreme importance; the clearly realizing of the dual nature of electricity and its action in a field of force, is the laying of a sound foundation for the whole structure of the comprehension of electrical action. As the question of surface action will be thoroughly examined, one illustration of the *apparent* confinement to *external* surfaces will suffice. Faraday used a conical bag of stiff muslin, provided with silk cords by which it could be turned inside out; and mounted on a metal ring supported on an insulating stand. If a charged body is introduced into the open mouth and touched to the bag, the electricity leaves it, and is found on the outside, on which all the little fibres will rise; no trace of any is to be found in the interior; if now, by means of the strings, the bag is turned inside out, the electricity at once passes to the other and now outer side. Faraday even showed that inside an insulated chamber built for the purpose within another room, and strongly charged with electricity, the most delicate instruments contained in it and connected to it showed no trace of action.

This experiment has been very carefully repeated by others also, but interesting as it is, and important as it was at the time, it only proves what is a detail, an instance of a general law. *The static actions of electricity are manifested at surfaces because these are the boundaries of the field of force in which the electric charge exists.* The law and its reason are obvious: Electricity in its static manifestations *must be found only on surfaces,* where the polarized circuit passes from one body to another; it is a state of strained rest, unmoving tension, and can only be discovered by transferring that state of tension to another body.

82. The two great authorities on electrical distribution and its consequences are Coulomb and Sir William Harris. The first examined the subject in the most elaborate manner, by means of the torsion electrometer, and arrived at certain conclusions which he embodied in a series of laws. Sir William Harris, on repeating the experiments, found Coulomb's results only approximately correct, and modified these laws accordingly, and to this hour the subject remains in this indefinite state, for in fact, any laws of distribution and accumulation can only be approximate; they are only general principles, and the distribution will vary with every variation in surrounding bodies, that is to say, with every alteration in the lines of *least inductive resistance*; so the charge will be found only on the external surface on an isolated body, if, as is usually the case, its polar circuit is directed to external bodies; but if an interior body is provided through which the circuit is completed, then electricity is to be found on the inner surface.

Spheres distribute the charge equally over their surface provided they are at a great distance from the opposing charge: two or more spheres connected, will divide a charge in proportion to their "capacity," which is as their radii, if regarded as isolated bodies.

Ellipses distribute the electricity more towards their ends as do a series of spheres in contact.

The form of the conductor influences the distribution simply by the relative facilities of generating lines of force to the opposed conductors, and the mode of testing the density is by applying a proof plane, which becomes the surface it covers, appropriating the lines of force terminating there, and constituting with them a new field of force of its own.

83. POINTS.—We have in this action of distribution the reason of the action of points. If the conductor of a machine is fitted with a point, no charge can be obtained; if a pointed conductor be held towards it, no charge can be obtained. The lines of force pass from every part of a surface towards every opposing surface carrying opposite charge: in the case of a sphere these lines are therefore radial and equal at all parts: in the case of an ellipse, they are parallel along its length and radial at its ends: in the case of a cone, they pass in all directions not covered by its base; and as this cone lengthens, they increase in number till a point terminating a long cone

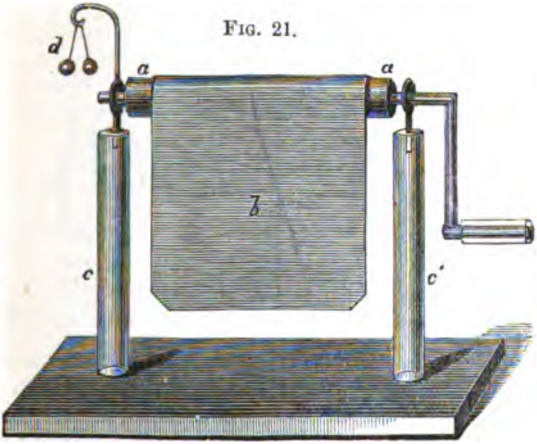
may be regarded as the centre of a sphere, concentrating upon it all the possible lines of force. All substances have their limit of endurance, *their breaking strain:* the dielectric strength of air has its limit, and under these circumstances it breaks down and becomes a conductor: the breaking strain of air is reached when the density approaches 20 static units (§ 72) per square centimetre: we may conceive that in these circumstances the molecules of air become so strongly charged that they fly off towards the surrounding surfaces. If the points are cased in guttapercha or other substances of greater power of endurance the limit of charge is largely increased.

It may be as well to refer here to the action of the electric whirl. This consists of a number of wires with their ends pointed and bent all in one direction, and fixed upon a centre point so as to be able to rotate. When this is connected to an electric source, it rotates rapidly, and if examined in the dark it will be seen that each point is giving off a brush discharge, which the motion converts into a luminous ring. This is commonly explained as an effect of repulsion between the points and the particles of charged air. There are probably two actions at work: the brush constitutes a negative attraction upon the metallic arms on one side, because the attraction is exerted on the molecules of air, therefore the active attractions remaining are on the other side of the arms: but as the particles of air are rapidly drawn away so as to produce a strong wind, an equal eddy wind is produced which acts in the opposite direction on the arms and produces rotation.

84. SURFACE DENSITY.—If we take two balls of 1 and 2 inch diameter and charge them both at the same time from one source, the 2-inch will have twice the "quantity" of electricity on it that the other has; but if we apply the two balls to an electroscope, they will both give the same indications, or if both are tested by proof plane and balance, both will be found charged alike. It is necessary therefore to see what will be the effect of altering the extent of surface without altering the so-called quantity of electricity. We can do this by the instrument shown, Fig. 21: *a* is a brass tube, one end fitted with a piece of metal from which extends a wire for the axis, the other end fitted with a plug of indiarubber, in which is secured a wire forming the other end of the axis, and bent into a winch; *b* is a sheet of tinfoil; *c* and c^1 are glass tubes, to the top of which are cemented wires bent round to serve as bearings for *a*; on *c* is soldered a wire hook to carry two pith balls. If the foil *b* be now charged in the usual way the electroscope will give an indication representing a given charge.

Now wind up the foil, and as the exposed surface diminishes the action is concentrated on that smaller surface, and the electrometer indicates accordingly; when the surface is reduced to half, the electrometer indicates doubled action: when the surface is reduced to one-fourth, the electrometer indicates four-fold action. But what is really measured by the electrometer in this case is not "quantity," nor even density upon the foil itself; this should be clearly comprehended. From every part of the surface, *the pith balls included* (or a separate instrument represented by them), lines of force extend to the opposing surfaces, and the tension on all these lines is equal: therefore we must regard the foil *b* and the balls *d* as *distinct inductive circuits*, the relative resistances of which are proportional to the relative surfaces. When the foil is reduced in surface to one-half, *its inductive resistance is doubled* or in other words its capacity is halved: the relations of the two circuits are now changed, the relative resistance of *d* is only half of what it was at first, and therefore twice the number of lines of force concentrate there: in other terms the surface density is doubled on both *b* and *d* and the electrometer measures *not the quantity on the foil*, but the action of its *own inductive* circuit: it measures the quantity on the foil and its density indirectly, but only because these bear a definite relation to the similar conditions on *d* itself. This is the point every student of electricity should firmly impress on his mind, that *every possible line of force in an inductive circuit has*

FIG. 21.



its own definite resistance and conditions; that each line of force is truly *a derived circuit,* and that it should be studied on exactly the same principles as rule the actions of a large number of wires of different kinds connected to a galvanic circuit, and constituting derived circuits for current.

85. One of Faraday's beautiful experiments illustrates many of the points hitherto considered. Let Fig. 22 represent a room containing *s*, a source of electricity, such as a machine, to the prime conductor of which is suspended a ball +, the rubber being connected to earth, that is to the walls, from which the radiating lines indicate the lines of electric tension set up in the air; *e* is an electrometer which if connected to + will show positive electricity by the leaves diverging; if instead of this *e* is connected to the walls, a feeble divergence will be manifested, but this time it will show negative electricity; this, however, will require a very delicate instrument, because although exactly the same *quantity* of negative electricity exists on the walls as there is of positive on +, the surface is so vastly larger, that the density is so low as to render its presence almost undiscoverable. See § 73.

FIG. 22.

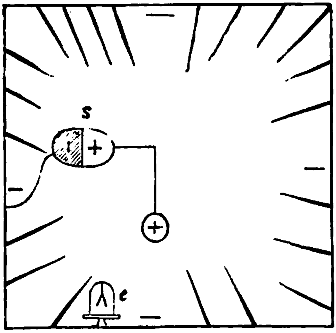
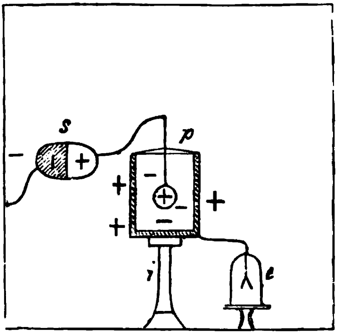


FIG. 23.



86. INDUCED CHARGES.—The experiment is further developed in Fig. 23, in which *p* is a metallic pail surrounding +, and itself insulated by the glass stand *i*. The pail is not in contact with +, yet on connection to the electrometer its outside is found to be +. In fact this experiment is in principle the same as those described § 90, and the pail will be found to have the same quantity of positive electricity on its exterior surface as + itself has, yet the latter has lost none; on the other hand, if + be now touched to the pail and discharged, *p* will receive

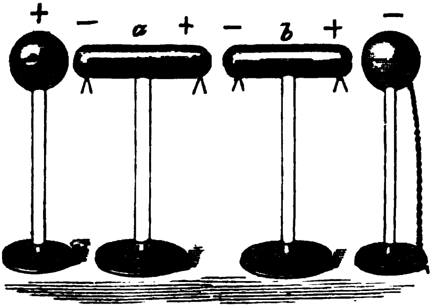
no more electricity, nor will *e* manifest any change in its condition, although + has lost all its charge. The reason is, that the pail when placed round + without contact, takes the place simply of the particles of air, and by presenting a change of substances, manifests the condition of polarization existing in the air it displaces, but not manifested or discoverable there, because these static effects are never exhibited within any substance forming part of the inductive circuit, but only at the points where that circuit passes from one substance to another, that is to say, at the surfaces in contact. In like manner we see no changes or action in the liquid of a decomposition cell or in the wires, but only at the surfaces of metal and liquid in contact. Thus it will be found that the interior of *p* in this condition is in a negative state, and this is usually termed electrification by induction; it is, however, embraced in the general theory that electricity is simply a chain of polarized molecules, and any molecules inserted in the chain necessarily become polarized. Instead of a single pail, several may be employed within, but insulated from each other, when each will show − electricity inside, + outside, and each will be found to have exactly the same quantity, with a density proportioned to its surface.

Several important conclusions may be drawn from this experiment. It is a fundamental law that no effect can be produced without a cause, energy equivalent to it being expended. But if the charged ball + be inserted into a set of pails, it polarizes them, producing a number of surfaces all charged with as much electricity as itself without itself losing any. Nay, if the ball be first inserted before charging, it will be found that it can be charged more easily than when the surrounding pails are removed. Now if induction were a fresh effort of force, it is clear that neither of these circumstances would occur. Why they do occur is evident on this theory. The resistance to polarization of the metal pails is less than that of the air, they therefore require no effort of force; on the contrary, the transfer of the state of tension from air to metal diminishes the energy expended in the action, or the inductive resistance of the circuit.

When it is said that the charged body loses no force, the statement requires explanation; it actually loses, but then every charged body does this, and in every experiment the tension is constantly falling at a rate dependent on the state of the air and surrounding objects; what is meant therefore is, that this normal rate of loss is not increased by the conditions of the experiment.

87. Exactly the same teaching is derived from the experiment shown in Fig. 24 which is commonly employed to illustrate "Induction," as though it were an action set up by a body possessed of free charge, while it really exhibits the mode in which the chain of polarization is developed. + is a charged ball on an insulating stand; if we imagine it standing alone, the conditions are those of Fig. 22, an equal quantity of – electricity existing on the walls; we now bring near it, but not near enough for a spark to pass, the insulated cylinder *a*. This furnishes a new path for the force, and its molecules are polarized, gold leaves or tinfoil suspended at its ends will diverge, and by examining their condition the charge at the end nearest + is found to be –, and the other end +. The common explanation is that the free electricity of the ball decomposes the natural electricity of the cylinder, attracting to its nearest end an equal quantity of the opposite electricity, and repelling the similar to the other end. Add *b*, a similar cylinder, and the same result occurs in it, and in as many as we please. Terminate the series by a ball similar to the first; it, like the cylinders, is polarized; but if by means of a chain or a discharger we connect the ball to "earth" for a moment, we find the ball is then charged with – electricity alone, and to continue the old explanation, its + goes to earth, leaving the free charge opposite to that of the first ball.

FIG. 24.

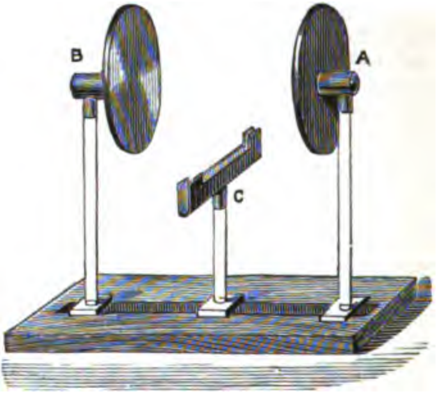


But the real explanation is this: When *a* is placed near the ball, it presents a more ready path for the force, because its molecules resist less than those of air, hence a twofold action. Its molecules are polarized by the force charged on the air it displaces, but also a disturbance of the previously existing arrangements is produced; instead of the polarization proceeding in all directions equally, *a* presents, by its enlarged surface, a much readier path, and the largest portion of the force tends to it, and will result in a spark passing if they approach too closely, while if this is avoided, a simple redistribution of the lines of force occurs. When *b* is added, a similar result and fresh distribution occurs; and again when the last ball is presented; but when this last is connected to earth, it sets up a circuit of small resistance, confined nearly to the line of balls and cylinders: there always is a partial circuit to the other surfaces, however, and in consequence of this the — charge on the last ball will never be equal to the + on the first, as the old theory would involve; if touched together in an insulated condition there always remains a charge on + which is equivalent to the – left on the walls, &c.; so also each successive cylinder will be polarized with diminished force, and will retain on removal a slight positive charge, if the final ball has been connected to earth, because from each of them a fraction of its circuit is completed by the walls instead of through its opposite end to the next cylinder.

88. Condensation.—We can now understand the action of charged surfaces in the form of condensers, such as the Leyden jar, and those used in induction coils, and in those vast condensers, submarine cables, in which these effects of charge produce the great retardation in the passage of signals, which long puzzled practical electricians. The instrument shown in Fig. 25 is intended for examining this subject. It consists of a wood or ebonite stand with a groove down its middle, in which can be inserted the stems of the other parts which can then be placed parallel to each other, and at various distances. A and B are glass or ebonite stems carrying metallic discs; C is a similar stem carrying a clip frame, which will support a sheet of glass or other dielectric. Now let A, standing alone on the frame, be charged from the prime conductor, it becomes +, and the walls – as usual, and gold leaves or pith balls attached to A will be repelled on both its faces. Now if B is placed as shown, it will produce no effect on A, but will itself be polarized exactly as were the cylinders in Fig. 24 and in a degree depending on the distances; depending, that is, upon the area of the inductive circuit or lines of polarization which its surface occupies. If B be now uninsulated by touching it, it will be found to be wholly negative. Thus far we only repeat the conditions of the case described in § 87.

But it will be found now that only the gold leaf on the inner side of A is affected, that on the outside will no longer be repelled: the reason is that the inductive circuit A B has a resistance so small, compared with the outer circuit, that the — charge has left the outer circuit and concentrated upon B: the old theory called this an induced charge which was supposed to be called up from the earth by the attraction of the + on A, whereas it is simply the actual — counterpart of the + inseparable from it, but constituting with it a field of force wherever it finds the least resistance, that is to say, where there is present at the shortest distances, matter having the most capacity for generating the field, or as the next stage of still lower resistance, matter capable of transmitting electric current.

FIG. 25.



If we connect A to the prime conductor, and B to the rubber, the whole apparatus and source being insulated so as to confine the action to this circuit, when we generate electricity electroscopes fixed to the inner faces will be repelled as usual, but those on the outer faces will be entirely unaffected. In this state we cannot discharge either of the discs by any earth connection, we can only slightly diminish the charge; if we touch A, a derived circuit is set up, and a portion of the positive charge passes to surrounding conductors, and the more distant apart the discs are, the greater this portion will be, because the charge will divide itself in proportion to the resistance of every path open to it. If we next touch B, a similar action occurs; first an amount of charge passes away equal to that removed from A, and then a negative charge takes its place; thus, step by step, the charge may be removed.

In these conditions, the plates A B (which exactly represent the two coatings of a Leyden jar) fairly correspond to the two plates of a galvanic cell; connecting one plate to earth, &c., is the same thing as connecting only one pole of a battery to apparatus. The only difference between these plates and those of a cell is that the battery plates are capable of constantly renewing their own charge, while the condenser plates have only that placed on them from an exterior source.

89. BOUND OR DISSIMULATED ELECTRICITY.—These are terms which belong to the old theories: they are meaningless under the new theories, but are still employed in text-books. When, as in § 87, the + charge acts by induction on the cylinder *a*, Fig. 24, it is said to break up the neutral electricity, to attract its – and to repel its + to the further end of the cylinder: this cylinder has then two charges of electricity, of which only the + will leave it when touched to earth. This + is called the *free* charge and the – is said to be *bound* by the attraction of the + ball. The real actions have been explained.

If we take the electroscope Fig. 8, p. 19, and attach the plate *f*, and place a similar plate upon it (the faces being varnished so as to represent the plates A B, Fig. 24), we have a condensing electroscope. If we apply a weak source of electricity to the lower plate, only a very slight action occurs at the leaves; if we touch the upper plate while the source is acting there will be *accumulation* in the condenser formed by the two plates, because its capacity vastly exceeds that of the highly resisting circuit of the leaves themselves, but as the potential remains the same the leaves remain unaffected; of course, the two circuits do not disturb each other, each acts as though it were alone. If we now remove the upper plate (after disconnecting the source) *the leaves expand.* Why? I quote from a recent work, "the capacity of the condenser diminishes enormously and the small quantity of electricity is now able to raise the potential of the plates to a higher degree and the gold leaves expand accordingly." The explanation simply obscures the natural facts. The plates have nothing to do with the matter; when the upper plate is removed the condenser ceases to exist, but there are two distinct circuits through the air to other surfaces; one circuit is from the surface of the plate, the other from that of the leaves: these latter (if there is an earth-plate, as shown, provided by the foil on the glass case) have a circuit of much the lowest resistance and the action concentrates there just as described in § 88 when the circuit is changed by diversion to the plate B of Fig. 25.

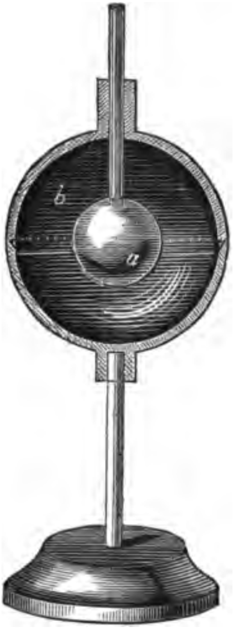
If the plates A and B of Fig. 25 are placed as far apart as possible they will only receive a certain quantity of electric charge from a source of a given potential, such as a battery: if we approach the plates, they will receive a higher charge, not because the two electricities attract each other more strongly and are therefore able to *bind* more of each other as the books say, but because the resistance of the circuit being diminished, a stronger field of force is generated, just as with the same battery a stronger current is generated when the length of the interposed wire is diminished. If the plates are brought near together, and charged as much as possible, then the placing of a sheet of glass upon C, Fig. 25, would enable a yet higher charge to be taken up, and a sheet of ebonite would yet further increase this "capacity for electric charge": this shows that the matter between the surfaces plays an important part, and the case is analogous to substituting a copper wire in a battery circuit for a brass one of equal size and length. Freeing our minds from the ideas of *dissimulation*, the molecular theory gives a clear explanation of the facts. The charge a given circuit can receive from a given source is in the *inverse ratio of the resistance of that circuit;* or, in other words, *proportional to its inductive capacity.*

90. INCLOSED SPHERE.—The action of a sphere inclosed in another sphere affords the most complete study of the principles of the inductive circuits, and it is so completely enshrouded in mystery in most of the text-books that it is desirable to examine it, although in so doing we are really going over the ground again. Fig. 26 *a* is a ball of metal mounted on a glass tube cemented into a neck on *b*, which is a hollow sphere divided in two at its horizontal diameter, so that the upper half may be lifted by the glass tube; the lower half is mounted on an insulating stand. If we now connect *b* to the prime conductor in the usual manner, it will receive a charge, and on lifting the upper half no electricity will be found on the inside of *b*, or on the ball *a*. Even if we insert a wire in the tube and connect *a* and *b*, *a* will receive no charge; but if the wire be left in *a* during removal, then charge will be found on it by transfer from *b*. This is one of the old experiments showing that charge resides only on *external* surfaces. But if we drop a wire through the tube into *a*, and charge it, connecting *b* to earth, that is to the rubber of the machine, then we shall find + electricity on *a*, and − on the *inside* of *b*, while the outside will show no signs of electricity. If the rubber is as usual connected to earth and also direct to *a*, while *b* is charged +, both inside and outside will be found charged *alike*, and the inner charge will be equal to the − charge found on *a*

and greater than the outer charge, this being due to the smaller space of air between the *inside* of *b* and *a*, as compared with that between the *outside* of *b* and surrounding bodies; we have in fact here two *inductive circuits* as in the other cases.

Again, if we charge *a* as before, and then by a discharger connect the wire leading to it with the outside of *b*, on removing the upper part no trace of electricity will be found remaining on *a*, if the rubber is connected to "earth." Further, if we charge *a* from the conductor, the rubber being to earth and *b* not connected to the machine at all, we shall find that its inside is in a – condition and its outside +, and this outer charge will be equal in quantity to that on *a*, and yet although the outside and inside are in intimate metallic contact, these two electricities will not re-unite as long as the charge is maintained upon *a*; here, *b* is under the same conditions as the pail § 86. This is a simple matter which the text-books render mysterious by the introduction of "potential." They say that no current passes from the outside of *b* to the inside, because although differently charged + and – *they are at the same potential*, the evidence that they are at this same potential being the fact that the current does not pass; this reasoning in a circle is unnecessary, and the use of the idea of potential here is misleading. If it were said that there was no *difference of potential* between them it would be merely a roundabout way of saying that the opposite charges on the sides belong to two entirely distinct circuits having no relation of potential between them at all.

Fig. 26.



When the circuit is internal, by charge having been given from the two poles of an insulated source, there is no external evidence of the presence of electric charge. There is no reason why there should be, but an elaborate explanation of the natural necessary fact is provided in the mathematical theory. As the action of charge upon a sphere is the same as if it were concentrated at the centre, § 93, it is argued that the + charge on *a*, and the equal – charge on the inside of *b*, having equal opposite actions from the common centre, neutralize each other's external actions.

91. LEYDEN JAR.—A little consideration will show us that the conditions of the Leyden jar are identical with those of the two spheres of § 90, it is a mere substitution of cylinders for spheres, and of glass for air: we may therefore examine some important parts of Electrical Theory by aid of these familiar instruments.

According to the mathematical theory of electricity, current, &c., discharge, &c., are due simply to *difference of potential*, the actual position of the two points on what we may call the "scale of potential" having no influence. When the word "potential" is used by itself it expresses the difference of potential from an assumed zero, usually the earth. Such a scale of potential is analogous to a vertical column of water in which different pressures may be obtained at different heights.

The same effect will occur between two points in an electric circuit, whether those points are at + 15 and + 5 potential as regards zero, and though both of them have free + charges, as would occur between two points at + 5 and − 5, with equal free + and − charges. The facts are, of course, true, and for some of the purposes of calculation, the theory has its advantages. But the theory is not true as a fact of nature. The water analogy itself disproves it; the column of water below the point at which current passes is inert, *it is not in the circuit.* But further, there is no such thing as a − pressure in the column of water except in view of the arbitrary zero, the earth surface; the real pressure is always +, always in one direction, and is related to the centre of the earth. It is the same in electricity; there is no actual + and − (as in the old fluid theories), these merely represent the relations of opposed sides in the *individual circuits alone:* the same point of space may be + to one circuit and − to another circuit, but these two circuits are wholly independent; the idea of a common scale of potential is purely arbitrary, artificial, and delusive. See § 77.

We may take the two supposed jars (15 + 5 +) and (5 + 5 −) and join the two external coatings together, no matter whether they be both + or one + and the other −, and we may then connect both to the supposed zero of potential, the earth, without producing any effect upon the charges.

To meet this fact the other artificial doctrine of *bound* electricity was invented, and this is dealt with § 89. But the jars in this case are exactly analogous to two distinct galvanic cells, which may be combined and connected in exactly the same manner without producing current, as long as the other poles (corresponding to the inner coatings of the jars) are not connected. Under these circumstances we can insulate the jars, either connected or separate, and we can give the external coatings a *free charge.* But what is this but adding a third inductive circuit? We can charge the external coatings + or −, but in so doing we simply make the outside surfaces the one coating to the air of the room to which the other coating is the surrounding surface. We can even put opposite free charges on the two jars in the same manner, and we can make these charges either the same or the opposite of the charges which their inner surfaces bear.

All this becomes perfectly clear when we examine each separate inductive circuit as we should the circuits of currents which every one knows may be absolutely distinct though they all unite at a common point, or even traverse some part of a common conductor: it is exceedingly difficult to comprehend when we encumber the facts of nature with a set of merely imaginary conditions, the only true function of which is to serve purposes of calculation. As to residual charge see § 94 (*i*).

92. INDUCTIVE AND CONDUCTIVE CIRCUITS.—At this point it will be useful to define the relations and contrasts of the static and dynamic actions of electricity, which consist solely in the different nature of the two circuits in which are set up the fundamental electric conditions of § 40, p. 26.

The *conductive circuit* consists of matter which allows electrical action to take place in the form of current, or we may say it permits electricity to pass. It does so in quantities related to the electromotive force, to the conducting capacity of the material substance, and in producing current the electricity expends energy.

The *inductive circuit* consists of matter which does not transmit electricity, but admits of the formation of a field of force manifested as *charge* at its opposite sides. Such "charge" is proportional to the potential, to the inductive capacity of the material called the dielectric, and in producing charge the electricity expends energy.

The tabular arrangement on the following page illustrates the relations very forcibly.

93. CAPACITY.—It is usual to define capacity for charge as connected to surface, and in fact the unit of capacity is, like that of quantity, a sphere of 1 centimetre radius; it is also taught that the capacity of spheres is as their radius; but this form of statement hides away the fact that the capacity exists, not in the sphere, but in the surrounding space itself, and that the dimension of the sphere affects the capacity only because it

Static	ELECTRICITY	*Dynamic*
Energy *potential:* stored in a field of force, as stress in a dielectric.	means	Energy *kinetic:* acting in a conducting path, along molecular chains.
Inductive	CAPACITY	*Conductive*
Area of dielectric.	varies as	Area of conductor.
Spec. ind. capacity of dielectric.		Specific conductivity of material.
Thickness.	inversely as	Length.
Units of Charge stored under unit Potential.	is measured by	Units of Current transmitted under unit EMF.
The Potential in Volts required for unit Charge.	or by	The EMF in Volts required for unit current.
Inductive	RESISTANCE	*Conductive*
Reciprocal of inductive capacity.	is the	Reciprocal of conducting capacity.
CHARGE	ELECTRIC	CURRENT
Potential, in Volts.	is as	Electromotive force, in Volts.
Resistance.	inversely as	Resistance.
Lines of force under stress.	is related to and dependent on	Lines of equivalent molecules forming chains.
Inversely as the several resistances.	divides among several circuits	Inversely as the several resistances.
	ENERGY, OR WORK	
Square of charge in unit or equal resistance.	is as	Square of current in unit or equal resistance.

FORMULÆ.

Charge	$\frac{E}{R} = Q$	Current	$\frac{\mathrm{E}}{\mathrm{R}} = \mathrm{C}$
Potential	$Q \times R = E$	Electromotive force	$\mathrm{C} \times \mathrm{R} = \mathrm{E}$
Resistance	$\frac{E}{Q} = R$	Resistance	$\frac{\mathrm{E}}{\mathrm{C}} = \mathrm{R}$

forms a connection to the space and the medium occupying it; therefore the expression is often qualified by the statement, "provided it is at a considerable distance from surrounding surfaces." Readers who have comprehended preceding explanations will understand that a sphere has no capacity at all, *considered by itself*, and that any statements referring to the capacities of single surfaces are merely artificial processes of calculation, not expressions of natural facts.

Capacity is measured by the electric quantity necessary to raise the charge to unit potential.

(*a*) *Spheres.* A sphere of one centimetre radius is taken as the unit of capacity in the centimetre-gramme-second system of measurement.

Capacity of spheres varies as their radii.

A charge on a sphere acts externally as though it were located at the centre of the sphere. See § 90.

(*b*) *Concentric spheres* have a capacity dependent on the relative radii r, measured by the formula $\frac{r \times r^1}{r^1 - r}$ in which r^1 is the outer sphere. The rationale of this formula is that it represents the capacity due to the product of the two radii, and inversely to the thickness of the dielectric, which is the difference of the radii. Now, if the inner sphere is a small ball, while the outer is represented by distant surfaces, a moderate increase of the radius of the ball does not much affect the thickness, or distance, so that the capacity varies nearly as the radius of the ball as in case (*a*); if the two spheres are very close, their radii only affect the formulæ by the corresponding surfaces, and the principal element is the thickness of the dielectric, and the result is the same as in (*c*) and (*e*).

The actual capacity in any given case is ascertained by multiplying the result by the specific inductive capacity of the dielectric inclosed between the two spheres.

(*c*) *Concentric cylinders*, such as Leyden jars, or submarine cables, have a capacity dependent upon their length and their diameters; that is to say, really upon the efficient thickness of the inclosed dielectric, and also upon the sp. ind. cap. The formula is $\mathrm{K} = \frac{k\,l}{\log. \frac{\mathrm{D}}{d}}$ in which K is the inductive capacity; k the sp. ind. cap. of the dielectric; l the length; D the outer diameter, and d the inner. The same formula furnishes the current-giving power of cylindrical batteries, because the logarithmic ratio of the cylinders expresses the internal resistance.

(*d*) For *pairs of plates* of any form the formula is $\mathrm{K} = k\frac{\mathrm{S}}{4\,\pi\,t}$. It will be instructive to comprehend the part played here by 4π. (π being used in all formulæ for the circumference ratio 3·14159.) In the case of a sphere the constant ratio of the force to the surface density is $4\,\pi$, and this is connected to the relation of the surface of a sphere to its radius, which is $4\pi \times r^2$; that is four times the circumference ratio, multiplied by the square of the radius. Now flat plates may be considered as parts of the surfaces of very large spheres, and the formula is derived from this artificial representation, combined with the treating the two charges as acting from the centre of the imaginary sphere.

(*e*) The formula can, therefore, be simplified by passing from abstract mathematical conceptions to practical conditions, by using unit dimensions and values. If we take one square foot as unit of surface, and one mil as unit of thickness, using the sp. ind. cap. of plates of those dimensions, the formula becomes $K = k\frac{S}{t}$, and furnishes the capacity in microfarads; k in this case is the unit value in Table I. p. 81. In this case t, the thickness of the dielectric, represents the infinitesimal difference between the two imaginary radii, and therefore the charge is inversely as the thickness, although the forces to which it is attributed vary as the squares of the distances, *reckoned from this ideal centre.*

94. DIELECTRICS.—All substances possess two properties in relation to electricity; all conduct electricity, but with very different facility: all offer a degree of resistance to transmission, and undergo a certain molecular stress: resistance and this susceptibility to stress are not identical, nor even proportionate, yet they have some relation to each other; substances which undergo *stress* and retain the strained condition when the generating force is withdrawn are called *dielectrics*, and the faculty of receiving this stress is called *inductive capacity*. See § 19, p. 15.

(*a*) *Inductive Capacity* or electrostatic capacity is measured in "microfarads," and *specific inductive capacity* is the degree of this property possessed by specified or unit dimensions of each particular substance. Inductive capacity varies with temperature, and is generally reduced by heating. It is connected also with the relation of substances to light, for the *specific inductive capacity* of substances is as the square of their *refractive index.*

(*b*) *Resistance of dielectrics* follows the same laws as in conductors; it varies as the thickness and inversely as the area; each substance has its own specific resistance, but in dielectrics it varies inversely as temperature; it is measured in megohms (million of ohms) on account of its magnitude, as compared with that of conductors.

Guttapercha is usually measured at 75° Fahr. as unity, and its specific resistance may become (according to Willoughby

Smith) 23·6 at 32°, and be lowered to ·2233 at 100°; but other values are also given, and no doubt much depends upon its purity. The resistance of 1 mil-foot is 1066 megohms.

Indiarubber varies in the same manner, but to only about one-tenth the amount; and the resistance of both increases with pressure. Its resistance for 1 mil-foot is 20,770 megohms.

(*c*) The product of the resistance in megohms, and the capacity in microfarads, of any dielectric, is a constant value at the same temperature, irrespective of dimensions or form.

(*d*) Dielectrics have each a specific *breaking strain*, or power of endurance (see § 83); when the "stress" exceeds this, the dielectric breaks down, and discharge occurs. Even thick glass may be pierced when a powerful charge is concentrated upon a small area by means of pointed conductors; such breaks assume a zigzag line, following the points which offer least resistance, or which have least capacity for stress, and the discharge may break off into several lines.

(*e*) The act of charge alters the dimensions of the dielectric. If a glass tube is filled with water, and a spark led into it by conductors, the water acts momentarily as a dielectric, and the act of discharge shatters the glass to pieces. The expansions and contractions which occur in a condenser are such as to enable audible sounds to be produced as in a telephone. When a transparent dielectric receives a charge it is found that the arrangement of its molecules is altered, so that it acts differently with polarized light, just as is the case when the magnetic field is formed in a transparent substance, and the degree of change produced is proportional to the square of the electric force.

(*f*) When a current is passed into a dielectric, there is at first a sudden rush, and then a slow, continuous flow, due to two causes.

1. *Leakage*, as it may be called, which is the true current, due to the actual conducting power of the substance, or to any accidental defects, such as the cracks in the guttapercha covering a wire.

2. *Soakage*. The dielectric appears to continually absorb the electricity, as though the condition of stress were at first produced in only the nearest and most yielding portions, and then it appears to be gradually developed throughout the mass. Hence, the inductive capacity of any dielectric will be found to be different, according to whether it is taken for a merely momentary charge, the value of the first rush, or after a prolonged electrification. For most purposes, it is the first of these which is of most importance.

(*g*) When a condenser is discharged, a corresponding current is produced; first a rush, then a slow, continuous current, which is the "soakage" coming out.

(*h*) It is possible even to send in successive reversed charges, which will follow each other into the mass of the dielectric, and will return as currents of alternate direction. This, also, occurs in long cables, into which successive + and − impulses may follow each other, and appear as signals at the distant end.

(*i*) *Residual charge* is a result of this action. On discharging a jar or condenser, the principal portion of the charge—that which is due to the first rush in charging—is instantaneously given up; that which would maintain the small current gradually distributes itself over the mass of the substance, and after a time a fresh discharge can be obtained, or several successive ones, each fainter than the preceding one. This residual charge affords evidence of the state of stress existing in the substance: if it is allowed to escape as a very small current through large resistance and a reflecting galvanometer, the spot of light returns slowly towards zero as the charge is given up: but if the Leyden jar be tapped, it flashes across the scale, owing to the sudden discharge. This action is exactly what occurs with a strained bar or spring.

(*k*) For use in condensers, the most useful dielectric is one possessing high resistance and high capacity. For telegraph cables, high resistance and low capacity are desirable, because the stored charges effected at each passage of current are the cause of "retardation," and limit the working power or rate of signalling.

For information as to the properties of particular dielectrics see also § 97.

95. RETARDATION.—When a conductor and a dielectric constitute derived circuits to each other, the ordinary laws of conduction are modified by a principle which distributes electricity on all the paths open to it: if the two poles of a battery are connected to the faces of a condenser having a resistance of many megohms, and also to a closed wire circuit of only a few ohms resistance, the current will only flow in the latter in the same proportion as the condenser is charged, and the discharge of the condenser at a break of circuit acts a counter E M F, resisting current on fresh make of circuit. When the condenser is charged, it no longer affects the wire circuit. This is what happens in a cable; the charge of the dielectric must precede the transmission of current, and the actual current transmitted is a rising one, due not to the electromotive force of the battery, but corresponding at each fraction of time to the potential to

which the condenser has received its charge: as a consequence, the full power needed to affect instruments is only gradually reached.

96. SPECIFIC INDUCTIVE CAPACITY.—This is the relative capacity of each substance compared to that of air in the same dimensions, dry air being taken for the standard, as water is taken for the standard of specific gravity. Faraday took up the subject in his practical way, using a condenser composed of one sphere inclosed in another, and with a tube-stem provided with a stop-cock by which the dielectric could be exchanged. The instrument is identical in principle with Fig. 26, p. 73. He employed two such pairs of spheres of the same size, one containing air and the other the dielectric to be compared, and charging both together from the same source, he measured the "quantity" absorbed by each, which, of course, gives the relative capacity; this was also accomplished by an indirect method—by charging one, then dividing its charge with the other, and ascertaining the reduction of potential resulting from the division of the charge. Other experimenters have used flat

TABLE I.

Dielectric.	Faraday.	k. Capacity of plate, 1 ft. square, 1 mil (·001 in.) thick.	Later determinations.	
			Boltzmann.	Gordon.
		Microfarads.		
Dry air	1·0	0·0323	—	—
Resin	1·77	0·0572	2·55	—
Pitch	1·80	0·0581	—	—
Beeswax	1·86	0·0601	—	—
Glass	1·90	0·0614	—	—
Sulphur	1·93	0·0623	3·84	2·58
Shellac	1·95	0·0630	—	2·74
Caoutchouc	2·8	0·0904	—	2·220
Guttapercha	4·2	0·1357	—	2·462
Mica	5·0	0·1620	—	—
Paraffin	—	—	2·32	1·994
Ebonite	—	—	3·15	2·284
Glass: flint	—	—	—	3·054
,, crown	—	—	—	3·243
			Silow.	
Bisulphide of carbon ..	—	—	—	1·81
Oil of turpentine	—	—	2·153	—
Petroleum	—	—	2·054	—

plates of measured distance, and availed themselves of the delicate modern electrometers; but the real values are even yet very uncertain. A full account of the determinations as yet published will be found in Gordon's 'Treatise on Electricity and Magnetism.' Specific inductive capacity is frequently expressed as that of a cube, but for practical comprehension, the most convenient form is thin plates as given in Table I., in which I have collected the most reliable and useful particulars. The value k can be calculated for any substance by multiplying that of air 0·0323 by the sp. ind. cap. of the substance.

97. INSULATING MATERIALS.—The following are some of the substances most useful in constructing apparatus:—

(*a*) *Asbestite* is a compound of asbestos and hydrocarbon, which is capable of being moulded into cells, &c., and can be worked in the lathe; it is not possessed of great mechanical strength, but can be used for stands, &c.; its surface does not appear to precipitate moisture, and resists the creeping of salts which is so troublesome in battery and other cells.

(*b*) *Ebonite* has powerful insulating and dielectric properties, but air and especially ozone react on the sulphur, and render its surface conducting, § 46. When warmed it softens, and can be bent into any form, which it retains on cooling. It is about the strongest of all electric exciters. It has been found to transmit some of the rays of light and heat, and has been utilized in some of the remarkable experiments in radiophony which will be described further on.

(*c*) *Glass* varies greatly in its properties, see § 46. Crystal, containing much lead, is a bad insulator, and all kinds conduct when heated. For most electrical uses the German glass is superior to English, see § 23.

(*d*) *Guttapercha* is used in very thin sheet for condensers and in coils, but paraffined paper replaces it: its porosity and absorption of water are great defects for general uses. As an insulator for wire it fails when exposed to air, because it oxidizes and becomes brittle; but when it is entirely under water it improves and appears practically indestructible.

(*e*) *Insulite* is a new material prepared from wood, cotton waste, and other forms of cellulose, which is said to be a good non-conductor and impervious to moisture and acids, and which being capable of moulding into any desired forms, will prove cheaper and more durable than guttapercha and ebonite.

(*f*) *Ozokerit* is a mineral substance, which by distillation yields a material closely resembling paraffin, and a pitchy residue, which is largely used for insulating wires, by saturating the cotton covering. Its inductive capacity appears to be slightly greater than that of guttapercha, but its insulating power is nearly tenfold, a matter of great moment in conductors for the transmission of currents under high electromotive force.

(*g*) ***Paraffin*** is a most valuable substance: recently melted into a block, it makes an excellent insulating stand; but it becomes permeated with minute cracks which ultimately allow moisture to penetrate. Its use in saturating wood and paper is described § 22, p. 18. It is also useful in batteries to resist the action of acids. If the stopper and neck of bottles are warmed, and a piece of paraffin allowed to melt upon them and rubbed in, the stoppers will not set fast, and they make the bottle perfectly tight; also the labels may be protected by warming over a Bunsen burner, or spirit lamp, sufficiently to melt and absorb paraffin. When solid, this is one of the best insulators, but its resistance lowers with warmth, and very much so when melted. If two silk-covered wires are wound side by side on a reel, one end connected to a battery, and the other to a delicate galvanometer also connected to the battery, the other two ends being kept apart, current will be found to pass through the silk; if the reel is now baked carefully, much less current will pass as the silk is dry: if the reel is now soaked with melted paraffin, a considerable current will pass, diminishing as the reel cools, and ultimately becoming inappreciable.

Paraffin forms a sulphur compound by displacement of hydrogen; this is a convenient mode of obtaining small quantities of sulphuretted hydrogen which is given off when paraffin and sulphur are melted together in a test-tube. The residue is a hard red substance which would probably prove useful for electrical purposes.

(*h*) *Shellac* is chiefly used as a varnish dissolved in spirit or mixed with resin and beeswax as a cement for closing vessels or uniting glass and metal. It is a conductor as long as it remains liquid.

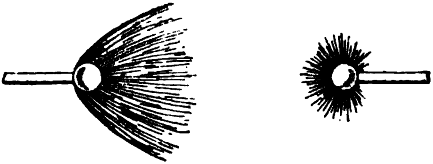
(*i*) *Vulcanized Fibre.*—This serves as an advantageous substitute for ebonite for many purposes, such as stands, tubes, and washers; it is much stronger, and does not soften with heat, nor is it an electric.

98. DISCHARGE.—So-called static electricity, which means in this aspect, electricity of great potential and tension operating across highly resisting media, develops a current of very short duration analogous to the bursting of a dam in the case of water. The various forms of lightning are natural instances of this disruptive discharge. The action may be considered as due to the independent action of the single pole, and this

was necessarily the earliest opinion, and is also the basis of the mathematical treatment: this doctrine would involve *unipolar discharge*, § 110. On the other hand we may consider discharge as perfectly analogous to electric currents, and as due to the combined action of the two poles, and impossible to be produced by one alone. But there is certainly a difference in the action of the two poles or so called electricities: if a discharge be passed through a card by pasting upon its two sides pointed pieces of tinfoil with their points not quite opposite, there will be a burr produced on both sides, indicating that the force is not a penetrating but a pulling one, acting by attraction from each pole; but the hole will be much nearer the – or negative pole.

But the principal evidence of this difference is found in the appearance of the discharge itself; thus the positive pole tends to produce a brush discharge, apparently spreading, while the negative tends to a bright concentrated star form. The effect is shown in Fig. 27.

FIG. 27.



The appearance is modified by circumstances, such as size of the terminals, and their form as balls or points, and the consequent relative densities, and lines of force, but still the *direction* of the passage produces different effects. A brush will be produced at the extremity of a wire if rounded off, in both cases, but the negative brush is much less defined than the positive. So with the star: if a pointed wire be approached to a large ball, a star forms on the point in both cases, because it concentrates the molecular action; but if the ball be +, the star continues till the point is close to it, only becoming brighter; but if the ball be –, as the point approaches, the star turns to a brush, see § 57.

99. One feature of electric discharge is, however, important to notice, because it is intimately connected with the theory of electricity; it is always attended with either mechanical motion or molecular disturbance. Thus as a general rule, when the discharge is occurring there is a stream of air from the dis-

charging points. This is shown in many electrical toys, such as the whirl, § 83. In other cases the molecular cohesion of the substances traversed by the charge is destroyed, as in the pierced card and the broken glass of an over-charged Leyden jar, § 94 (*d*). These effects are similar to those of lightning; thus, if a piece of wood have two wires inserted in it so that the points approach, but are separated by a stratum of wood, a strong charge passed will shatter the wood to pieces.

100. Further study of the electric spark will also show us that a molecular decomposition of the discharging surface occurs, and an actual combination of its materials is produced like the actions displayed in electrolysis. If two pieces of gold-leaf or tinfoil be placed on paper with the ends slightly separated and firmly pressed between two non-conducting surfaces so as to limit the direction of discharge, it will be found that the metal is detached and spread in minute particles over the interval. So in the electric light a constant stream of molecules of carbon is detached from one pole and carried to the other, the interval being filled with carbon in the state of vapour or gas or absolute molecular division—which is, by-the-bye, the only case in which pure carbon gas is known to be produced.

Again, the colour of the spark is modified by the nature of the surface giving it, each metal imparting its own colour; and if the spark is examined by the spectroscope we find evidence that it is not electricity itself passing in a visible form, as is occasionally suggested by those who believe in the actual existence of electricity as a quasi-material substance or fluid. The spectrum consists of bright bands varying in their character at different parts of the space across which the spark passes; close to the electrodes these bands are those belonging to the metal of the conductor; these weaken and disappear as the distance increases, and are replaced by those of air or other gas in which the discharge occurs, mingled with others due to the particles of matter floating in the air: the spark consists therefore of the matter which it traverses and renders incandescent.

101. The *length of spark* depends on the difference of potential between the discharging balls: but not according to a definite ascertained law, as in the case of currents; that is, the distance is not in the ratio of the potential. The fullest information we have on this subject is derived from careful experiments by Mr. Warren de la Rue with a battery of 14,400 chloride of silver cells, which are described in a paper read to the Royal Institution and reprinted in the *Electrician*, vol. ix. p. 77.

With 11,000 cells or a potential of volts 11,330 a spark of 0·62 inch was obtained between points, and below that force it was found that length of spark varied as the square of the potential (which is as the force, § 74). But with discs and other forms of electrode this relation does not hold. Upon these data it would require a potential of volts 3,604,000 to produce a lightning flash of 1 mile in length.

102. *Diminished pressure of air* lengthens the spark in the inverse ratio of pressure: but Sir W. Thomson and Mr. Gordon find this holds only down to a pressure of 11 inches of mercury. That is to say that "greater E M F per unit length of air is required to produce a spark at short distances than at long," or according to Mr. Gordon, "at low pressures than at high." Both observers say that "it is difficult even to conjecture an explanation." However I will venture a suggestion. Probably the particles of air are attracted to the two balls and held there in denser strata; certainly the lines of force concentrate upon the balls: the greater the distance apart the less effect this concentration must have on the total resistance, and therefore this may be expected to form a curve dependent upon the ratio the denser portion of the field bears to the total length of the field of force and line of discharge.

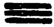
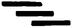
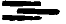
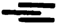
At a pressure of about 15 inches the spark discharge tends to pass into a brush which fills the tube: and as the pressure diminishes the phenomena to be observed in "vacuum" tubes are developed, while the colour of the light and especially the spectrum it generates, are those of the gas contained in the tube.

103. DURATION OF SPARK.—In 1834 Wheatstone employed an ingenious apparatus (on the same principle as one of the modes for measuring the velocity of light) to measure the time occupied by an electric discharge, and also what he supposed was the velocity of electricity. The principle is susceptible of many useful applications. If an object is seen reflected in a mirror it is seen in its true proportions, i.e. a point of light will be seen as a point thus • If the mirror is so mounted that it can be moved rapidly on an axis, this point will be seen in the mirror as a line thus ——. But if the point of light has an existence so momentary as to answer the mathematical definition of a point no velocity of motion will change its reflection from • to ——, and any such prolongation will be proportionate to the actual duration of the light itself, and therefore such duration will be calculable from the angular motion of the mirror while the —— is visible. By this means it was ascertained that the duration of the actual discharge of a

Leyden jar was 1-24,000th of a second: it would seem however that this time must vary with the quantity of electricity and the conditions of discharge.

104. Velocity of Electricity.—The same apparatus was applied to measure the rate at which electricity traversed a conductor; a series of balls were arranged upon a spark board; that is upon a disc in the same plane as the axis of the mirror, so as to form three spaces of 1-10th inch across which sparks would pass (* * *) after traversing fixed lengths of wire, the arrangement being such that the sparks 1 and 3 represented the ends of the circuit and the spark 2 its middle. The manner in which the sparks are drawn out would show the time occupied in transmission. From the result it was concluded that the velocity of electricity was 288,000 miles per second. This deduction was erroneous and all sorts of velocities have been found; no measure can be made, because of the "retardation" caused by the induction effects, § 95. It is known now that if the velocity were measured in this manner in a mile of wire stretched in one length and back again and then in the same wire wound in one length upon a reel very different values would be found, and different values if the reel were of large and small diameters.

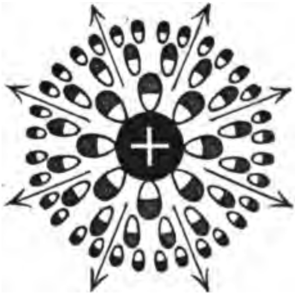
From the various relations of electricity and light it is however nearly certain that the true velocity independent of inductive retardation is the same as that of light, viz. about 185,000 miles per second.

105. Dual Nature of Electricity.—If the electric current were instaneously developed in the whole circuit, the appearance of the three sparks in the rotating mirror, § 103, would be either ⁝ or  according to the period of their existence. If electric transmission resembled a current of water, and starting from one end of the conductor flowed to the other, passing successively at each opening, the appearance would be  But this is not the case; the appearance is either  or  according to the direction of rotation of the mirror. This admits of only one explanation: *the electric current is generated equally at each end of the conductor and flows to the middle.* The working of long telegraph cables shows that momentary electric impulses are of the nature of a wave of influence, such as may be produced by a shake on a rope; the wave travels onwards by virtue of the energy imparted: in cables such successive impulses can be so sent as to follow each other, even though of reverse directions, each travelling independently along the cable and appearing successively at the distant end, resembling the action of dielectrics, § 94 (*h*).

An examination of Fig. 13, p. 34, will explain the nature of the electric impulse. We may consider the middle line of the molecule *a* as being the *locus* or point of origin of the electromotive force; it would be the surface of contact of a friction apparatus or the face of the zinc plate of a galvanic battery, the point at which energy is transformed into electric force. The polarized molecules at once exert their inductive power *in each direction*, each acting through all the lines open to it and necessarily passing into those of least resistance, where the conditions of neutralization consist in closing what in chemistry would be the open attractions (§ 9, Figs. 4 and 5) by which the molecules are constituted. It is from this starting-point in fact that the two treatments or conceptions of the nature of electricity diverge.

106. POLAR ACTIONS.—All the known facts of electricity show that it is a dual action. All the theories—the two-fluid, the single fluid + and −, or the molecular theory, which considers the two electricities, or rather electrifications, as merely the two sides or ends of polarized matter—agree in this. But the mathematical treatment is based upon single and independent actions; this is the meaning of that theory of the earth's action, either in the generation of electricity, in induction, or as return conductor, which regards the earth as a reservoir and sink, from which we can draw or into which we can discharge either + or − electricity separately or independently, even though in equal quantities at different parts, and some experimenters have sought to prove the existence of *unipolar actions* such as accord with this treatment, § 110. In Fig. 28 we have the picture of such supposed actions. The independent pole +, acting as a radiant point, *induces* polar order in

FIG. 28.



all surrounding matter. In such an action it is clear that each circle will be an *equi-potential line*, with no tendency to side actions, that is, not from any reality in the potential conception, but simply because the force is radial only, and every particle of matter takes up what force its position presents to it. Every such circle will have equal force acting from it, also radially, and, therefore, the force at each point of each circle will be inversely as the square of its distance from the centre. That is to say, the tension on each molecule in the lines of the field of force thus generated will diminish as the square of its distance.

107. Now, we have a perfect physical analogue of this. Let a level plane surface receive a supply of water at its centre, and it will flow outwards in all directions in this exact manner, and its distribution upon and velocity of flow will be identical with the conditions of Fig. 28, in which I have endeavoured to represent the facts by the diminished size and increasing number of molecules as the distance increases.

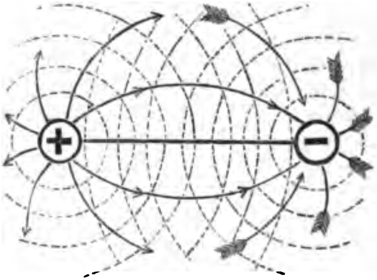
If we now conceive of some condition which puts this plane surface out of level, the flow of water will at once be altered into an elliptic system, narrowing the more as the inclination increases. If we conceive the plane as perfectly balanced on its centre, any cause which induces the water to tend, however slightly, rather in one direction, will at once cause the plane to cant over, and direct the line of flow more and more in this direction.

Just such an influence we have in electricity. *The second radial system — is always somewhere;* it may be conceived as a second system similar to Fig. 28, but with the direction of the arrows, representing the lines of force, towards instead of from the centre, and the molecular order reversed as regards the — pole.

108. Therefore the circles of these two fields must ultimately meet, and then the lines of force will attract each other with an effect similar to that of tilting the water plane, that is, they convert the two supposed independent radial points into the foci of an ellipse, and the imaginary radial lines into the curved lines of a closed field of force. I have endeavoured to show this action in Fig. 29. It is evident that as soon as the circles of influence cut each other the molecules are subjected to the influence of both foci, generating tension in the same direction. Now, pictorial representation cannot convey directly the well-known fact that the electric force exerts itself in the direction of *most capacity*, and this, as well as the law of inverse squares, will, therefore, concentrate the action into the space inclosed by the arrows.

This process of induction occurs in the lines of most capacity, or reciprocally, of least resistance, and, therefore, if there be a good conductor in the line, that becomes the shortest path, and is represented by the thick line between + and –. Along this line the constant charge and discharge, or molecular interactions, which we call *current*, is propagated. But the external induction is maintained as a condition of static stress or tension, and constitutes the inductive circuit around the conductor, taking a static charge corresponding to the forces exerted at each point, and the capacity of the medium.

FIG. 29.



109. We may therefore consider this inductive process as a kind of search for the point of union, and as preceding the actual generation of what can be truly called electricity. When we remember that the inductive propagation has a velocity of 185,000 miles per second, § 104, it is easily understood that even though the circuit has to be developed (as in cables) over a path of several thousand miles, the formation of the beginning of current, § 95, is instantaneous, especially as the inductive circuit really starts from two adjoining surfaces and can spread, not in full circles, as in Fig. 28, but in gradually advancing arcs similar to the dotted lines of Fig. 11, p. 27, which we can conceive as rapidly running along the cable, of which for this conception we can consider the molecules *a* as representing the conductor and those of *b* as the sheath.

110. UNIPOLAR DISCHARGE.—There have been many instances brought forward to prove that electric action can occur from one pole alone, but these are all equally consistent with the dual explanation: it is however certain that electricity has different actions at and from the two poles, which differences are manifested in forms of discharge, in greater heat at one electrode than the other, and other instances which will be met with: these differences are embodied in the idea of a *direction* of

electromotive force, in that of current, and that of the differing polarity of substances. One of the best instances of apparent unipolar action is contained in a very interesting paper by Messrs. Spottiswoode and Moulton (Phil. Trans., 1879, p. 165). They connected one end of two vacuum tubes (constituting derived circuits) to the − pole of the coil, and the other ends to a ball fixed at some distance from the + pole, so that the current was more interrupted and shorter in duration (as due to a spark) than if coming direct from the wire in a closed circuit. The spark selected one tube rather than the other for its proper path, and in the other tube it only produced a glow extending half-way along it in a reducing cone. Of this tube they said that the discharge in it is, in fact, one which leaves the + pole and enters the tube, but not with sufficient force to pass through it, and which returns on itself. But there is a simple explanation accordant with the universal facts of electricity. The tubes are not quite equal in resistance, or some accidental circumstance in or around them transforms the partial discharge through one tube into a circuit through and along the glass of the tube itself. The authors took the trouble to prove this without seeing it, for they made a tube with an intermediary electrode connected to one of the end terminals and to the + pole, the other end going to − pole. The circuit might be expected, in this case, to confine itself to the latter half of the tube, but actually two cones formed in the other half, representing opposed unipolar discharges. These are evidently a double derived circuit closed on the glass of the tube. This, also, the authors proved without seeing it. Returning to the two-tube experiment, they attached an external conductor to the + pole, and approaching it to the exterior of the tube, just beyond the supposed unipolar cone discharge, they drove it back and stopped it. Obviously, they added an external counter force which, preventing the completion of the circuit, prevented also the discharge. The case is precisely like getting a shock from one terminal of a coil, the circuit completing itself through the partially conducting supports. The conclusion of the authors, that each terminal pours forth its electricity to satisfy its own needs, and only in a secondary degree to satisfy the needs of the other terminal, must be exchanged for this other conclusion, according with all the facts of electricity, that as electricity divides among all the paths open to it, each terminal finds its circuit to the other, either directly or indirectly, by conductive or by inductive processes, but that *each takes equal part in every act of discharge*, and cannot generate electrical discharge until it has found a circuit uniting it to the other.

CHAPTER III.

MAGNETISM.

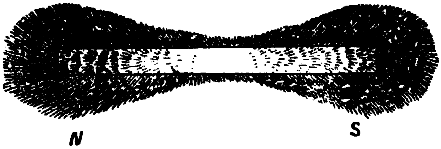
111. The purpose of this chapter is not to treat of magnetism and its phenomena on their own account, but only to deal with them so far as they are connected with or throw a light upon electricity. Further information will be found also in the chapter on Electro-magnetism.

The magnetic property of a natural substance, ferrosoferric oxide F_3O_4 or Fe O + Fe_2O_3, known as the loadstone, was discovered in early times from its power of attracting and adhering to iron. It was afterwards discovered that the loadstone imparted its powers to steel, and that masses of steel thus acquired a variety of peculiar properties besides that of merely attracting iron.

The first striking property is a directive power by which a bar of magnetized steel always places itself in one position, with one end pointing towards the north; the next is that when two such bars approach each other, two of the ends attract and two repel each other, instead of displaying a constant attraction, as with iron.

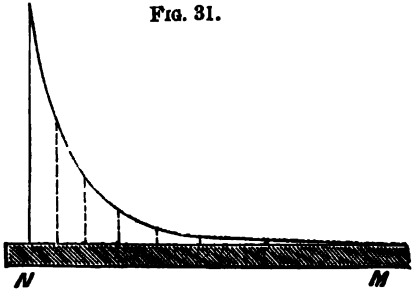
112. In examining these properties we find that the force, be it what it may, which is acting, is concentrated mainly at the two ends of the bar, towards which the holding power on iron is greatest; thus, if a bar magnet be rolled in a mass of iron filings, these will adhere to it in the manner shown in Fig. 30;

Fig. 30.



so if it is measured by the actions on a suspended needle, the force is represented mathematically by a curve shown in Fig. 31, which exhibits half a bar magnet, and shows that the point of greatest force, or what is called the pole, is not at the actual extremity, but a distance within, varying with the length and form of the magnet. These figures are identical with those which represent the distribution of electricity according to the laws discussed in § 71, and hence there was early perceived a relation beween magnetism and electricity, and this naturally, in times when men never hesitated to create any power which would serve to explain a fact, led to the hypothesis of two magnetic fluids, the Austral and Boreal, now entirely abandoned, although their brethren, the electric fluids, are still cherished by many philosophers.

FIG. 31.

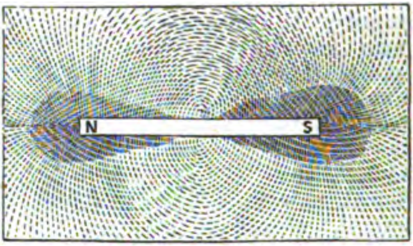


113. A remarkable feature in magnetic force is that it apparently acts at a distance without relation to intervening substances, providing these are not themselves magnetic. Different substances such as iron, nickel, and to some slight extent all bodies have *magnetic capacity* in varying degree, but this is unlike electrical capacity: in electricity all materials have equal capacity as to the surface charge, § 93, but different capacities as to forming the field of force, § 96; in magnetism the different capacity is in receiving and retaining the charge of force, while the surrounding field forms equally in all bodies not themselves magnetic. Hence a magnet acts just as powerfully through a sheet of glass as through air. If therefore we place a sheet of glass over a bar magnet, and sift iron filings over it, these arrange themselves in obedience to the force, if we lightly tap the glass to aid them in moving. Fig. 32 shows the result, the filings arranging themselves in closed curves which exhibit the lines of force surrounding the magnet, and on which, or, rather, on the tangent to which, at any part, a suspended magnetic needle will place itself. This figure represents therefore a section of a magnetic field; the field itself of course extending round the magnet in all directions. It also enables us to perceive that magnets do not act simply at a distance; they induce in all surrounding matter a condition which is the source of magnetic action; but it is only some forms of matter, of which iron is the most important, which render this condition

active as magnetic force, and are themselves capable of retaining that condition, and transmitting it afresh.

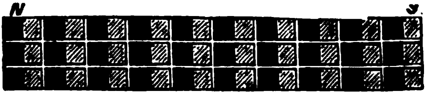
The forms or curves which may be obtained in this manner vary infinitely according to the position of the several poles in a field: they are in fact formed upon precisely the same principles as are shown in Figs. 20, 29 and render visible in magnetism the lines and fields of force which can only be perceived by the imagination in electricity.

FIG. 32.



114. To understand the magnetic condition, we must examine the magnet itself. Thus far we see in it a repetition merely of the electrified cylinders in Fig. 24 with the + and – charges apparently collected upon their separate ends. If, however, one of those cylinders is divided across the middle, we obtain the two parts in the opposite states, one wholly + the other wholly –, and there is thus some ground for the idea that we have really separated two fluids; but this is not the case if we break a magnet across, for we find that two perfect magnets are produced, two fresh and opposite poles being generated out of the previously inert middle, while the forces these possess are taken from the original terminal poles, the attractive powers of which are reduced. We may repeat this process to an unlimited extent, till we convince ourselves that the perfect magnetic power resides in every minute particle; in fact, that magnetism is a force belonging to and residing in the molecules of which the magnet is composed. This view of the nature of

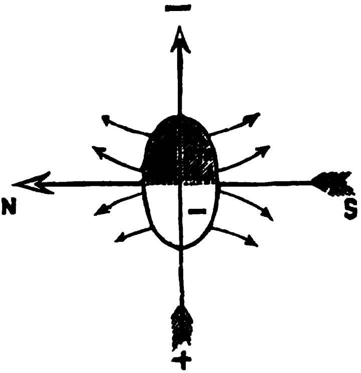
FIG. 33.



a magnet is well expressed by Fig. 33. This presents the magnet as consisting of a collection of polarized molecules symmetrically arranged, the force of each series exhibited at its two ends, and completing the circuit of polarization or force through surrounding matter in the curves shown in Fig. 32. This conception is strictly correct as to the facts of magnetism itself; but when we come to the theory and to the evident connection of magnetism and electricity, it is apt to generate confusion of ideas, owing to the apparent resemblance between the polarized molecules in both cases.

115. To avoid this confusion, and more intelligently to examine the facts and the true relation of the two forces to each other, and to the molecules of matter, it is desirable to define those relations in accordance with the views arrived at as to the relations of electricity to matter. Electricity and magnetism then are the same force, and are two actions of polarized molecules, manifested at right angles to each other, and both developed together. Electricity is the action which occurs *in the line of polarization*. Magnetism is the action which occurs *at right angles to the line of polarization*, and in all directions at right angles to that line. But there are some important distinctions to be noticed. Electricity is essentially a dynamic force, its nature consists in producing motion in, and transmitting energy along, the polarized chains; its static actions are only incidents of this process dependent on the resistance offered to the completed motion. Magnetism is on the other hand purely static; it consists in the storing up of energy in the polarized molecules. It should also be remarked that while magnetism is an essential consequence of and attendant upon electric polarization, it is only manifested as magnetic action by certain substances which possess the faculty of assuming that condition which constitutes a magnet; of these iron, nickel, and cobalt are the most effective, and this state is only produced and manifested by dynamic electricity, and in

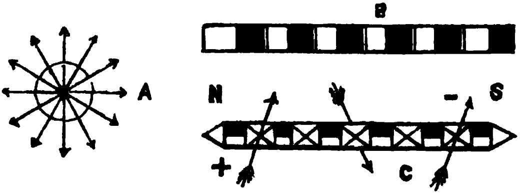
FIG. 34.



degree proportioned to its quantity. Considered from this point of view, Fig. 34 represents a typical molecule, and this figure thoroughly mastered and fixed in the memory will answer every possible question as to the relations of magnets and currents, the action of helices, galvanometers, coils, &c. A magnet will always place itself at right angles to such a molecule (forming of course part of a polarized chain), with its north end to the left hand, looking from the molecule itself, so that the arrow or magnet N S is supposed to be on the farther side of the molecule. There is, however, no true directive force in this action, no north and south *sides* to the molecule itself, as there are + and − *ends*, but the directive tendency is the same at right angles to *any radius* of the molecule at right angles to its line of polarization. Thus, if the molecule or current be vertical, and a suspended needle be carried round it, the needle will retain the same relative direction to the molecule, but will make an entire revolution on its own axis, and its extremities will point in turn to every direction, provided the directive action of the earth is neutralized, as by a fixed reversed magnet.

Fig. 35 will illustrate this. A shows a section of a conductor carrying current, or of the molecule in Fig. 34 with its radial lines at right angles to which external magnets will place themselves. B represents a filament of a magnet such as is shown in Fig. 33 which conveys a correct idea of the *magnetic* polarities in successive sections, while C exhibits the circular polarization in these sections, which is the probable electrical cause of the magnetic force: the arrows show the directions of a current which would set up this polarization, and generate the N S magnetism shown.

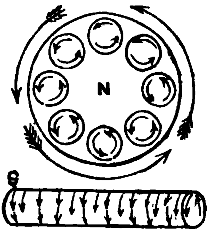
Fig. 35.



By aid of these figures the student may realize the idea usually employed since Ampère devised it in order to fix on the memory the relations of magnets and currents; for let the reader conceive himself *to be the molecule* Fig. 34, the current, of which he forms part, entering at his feet, his head therefore being the + extremity; his right hand will have the magnetic actions of a N pole to any object at which he is looking, and therefore any magnet in front of him will present its N end to his left-hand, the magnet itself standing fairly across him in front in whatever direction he may turn.

116. Ampère's Theory.—As before remarked, magnetism was formerly explained by the invention of two fluids; but the theory now generally received is that of Ampère. Working from the fact that a circular electrical current constitutes a magnet at right angles to its plane, and that electro-magnets are practically composed of a series of such circular currents ranged in the form of helices, and also from the fact that the force is evidently possessed completely by the molecules of permanent magnets, he taught that magnetic substances are composed of molecules around which electric currents are always flowing: that in the unmagnetized condition these molecules and currents are arranged hap-hazard in all directions, and that the act of magnetizing consists in arranging them in parallel order. Fig. 36 exhibits this theory; it shows the magnet built up of the molecules with their currents acting as does an external current shown by the arrows. The bar S shows a longitudinal view of the same magnetic system. The theory explains all the facts of magnetism, but beautifully scientific as it is, there are fatal objections to it, not generally seen. In the first place, it is based on the idea of electricity being an entity, a something which can circulate round the molecules in a real stream, and therefore it is inconsistent with more recent views as to the nature of electricity; but apart from this, though we might assume it to be possible that such circulating currents might be confined to the molecules, it is impossible to conceive how they fail to arrange themselves symmetrically always, or why, once arranged, as in magnetized iron, they derange themselves at once the moment the inducing magnet is withdrawn. The very nature of electric currents would require a *coercive force* to prevent the magnetic condition being always existent, whereas the reverse is the fact.

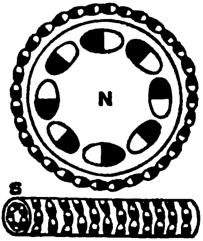
Fig. 36.



117. The Molecular Theory.—The theory of electricity set forth in the foregoing pages is equally adapted to magnetism,

takes possession of all Ampère's work, and adopts all the facts and all the mathematical problems and proofs based upon them; all of these are unaffected by the substitution for the assumed circulating molecular currents, of the conception of the polarized molecule exerting influence upon all the neighbouring molecules and arranging them in systematic polar order. Fig. 37 shows at a glance both the resemblances and differences of the two theories. N shows the molecules retained as a polarized chain, analogous to the conditions of static electricity, and it shows how an electric current generates this state in a bar around which it circulates. The coercive force of the magnet is due to the resistance of the molecules to the change of condition, either to being magnetized or demagnetized in the case of steel, the molecules of which are compound, while iron has little power to resist either. What gives the molecules of iron and steel these properties we do not know. But certain properties are apparently connected with the atomic weights of the elements, which have been classed into groups dependent on numerical relations of these weights. A Russian savant, M. Mendelejeff, has found some difference of properties according to whether the atomic numbers belong to an even or an odd series, as to which information may be found in the second supplement to Watts' 'Dictionary of Chemistry.' It appears that magnetic bodies all belong to the even series, and that diamagnetic bodies belong to the odd series, and that as to these latter the diamagnetism increases with the atomic weight.

Fig. 37.



118. Those who desire to study magnetism thoroughly, will find some useful suggestions as to experimental means in papers by Dr. Shettle to be found in vol. iii. pp. 10 and 44 of the *Electrician*. His object was to show that magnetism is a spiral force rather than a longitudinal one, but his theory involves, like Ampère's, a continually maintained current of energy, and it is difficult to conceive how such a current can be maintained. The spiral order of the molecular arrangement both as to magnetism and electricity may be almost considered to be established by the experiments of Professor D. E. Hughes, who gave to the world the microphone and the induction balance: he has proved that the passage of a current through an iron wire produces in it a permanent molecular strain, which is evidently of the nature of a twist or spire, the direction of

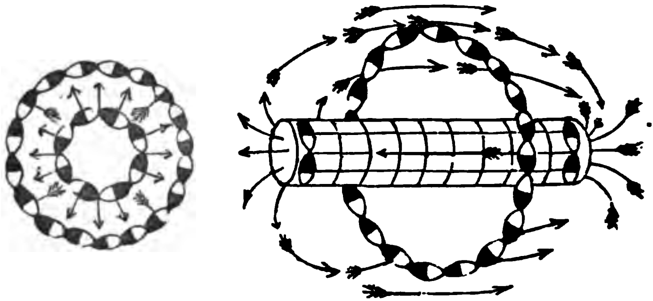
which depends on that of the current: this twist can actually be removed by a mechanical twist in the opposite direction, or by the application of a magnet pole. He also proved that this molecular twist, in the act of being untwisted mechanically, generates an electric current, just as does the ordinary cessation of magnetism. Professor Hughes has recently extended these observations in examining the nature of steel as an alloy of carbon and iron, and into the effect of "temper." His results promise important practical teachings and useful modes of testing the quality of steel as suited to different uses, and his papers should be studied by those interested in these subjects. The apparatus for the investigation is very simple: it consists of a tube with a coil of wire upon it, through which the wire to be examined passes and becomes the core of an electro-magnet; a battery and an interrupter is connected either to the coil or the wire, and a telephone to the other; each mode of connection has its use according as it is desired to observe the molecular effects produced on the core by a current, or the reactions of the wire in generating currents in the coil (when the battery would not be used) under the influence of torsion.

119. A magnet is usually thought of as merely a piece of steel in which a certain force resides: it is evident that this is only a part of the magnet; the external field of force which accompanies it is as essentially a part of it as the steel itself, and the actions of magnetism are all of them merely transfers of the energy of this field and rearrangement of its lines of force. The directive energy of the magnet is due to the inductive action of the energized molecules, tending to range all neighbouring molecules in the same order as themselves. They thus set up a magnetic field (which is a resolution of the forces exerted by the various acting molecules) in which all the particles of air and common matter range themselves, like the filings in Fig. 32: when a magnetic body enters this field its molecules range themselves in obedience to it, and by their own power set up a field of their own; when the body entering the field is already magnetized permanently, and therefore has its molecules already so ranged, or is temporarily magnetized circularly by being the conductor of an electric current, then if movable as a mass, it is turned or attracted or apparently repelled in such manner as to most energetically form part of the original lines of force or magnetic field; but if it cannot move it reacts upon the field and moves the magnet if movable, and a new field is set up which is the resolution of the forces of the two or more magnets within it.

120. **Magnetic Field.**—It is of great importance that this

conception of a "field of force" should be thoroughly realized and replace the old fallacy of a repulsive *force* because this supposed force is very apt to mislead in many directions, and it is well to see that throughout all nature we find no trace of a repulsive force, and therefore ought never to apply the idea to any phenomenon merely because it offers an explanation. The action of magnets is the strongest apparent evidence for the existence of such a force, and this makes it the more desirable to show that no such force is necessary to explain the facts. Fig. 38 will convey the idea of a magnetic field, in end view and perspective. It shows the magnetic bar constituted of the annular (or spiral) systems of statically polarized molecules as in Fig. 37. These molecules manifesting magnetic force at right angles, and their actions uniting in the aerial line of the magnet and developing the lines of magnetic force as shown in the arrows: the external "field of force" is developed, under the general law of inductive action by circles of polarization in the opposite direction to those of the magnet itself; the magnetic lines of force of these therefore attract, and form closed lines of force with those of the magnetized bar. The external arrows therefore show the position in which another magnet would necessarily place itself, *because in so doing the lines of force of the second magnet would place themselves in those of the principal field.* The lines of force of magnetism, like those of electricity, tend to the direction of most capacity, so that whenever a magnetized or magnetic body enters the field, the lines of force concentrate within it, and the external actions are to that extent suppressed, This is just what happens when an armature is applied to a horse-shoe magnet. In the case of a horse-

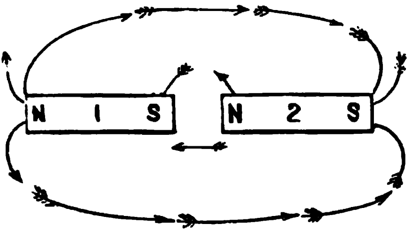
FIG. 38.



shoe the external field forms itself in the space around the opening, forming an ellipse, with its circles of polarization in the same order as those of the magnet (instead of reversed as in Fig. 38 where the magnetic lines have to return on themselves): on the approach of the armature the lines of force are taken up by the iron, which becomes itself a magnet forming a continuation and completion of the horse-shoe: the energy of the external field develops the force of attraction, and if the armature is sufficiently large and in very good contact, the magnet now ceases to have any external action, because its whole circuit is self-contained. This never occurs completely in the case of an armature, because perfect contact is not to be attained: but if a homogeneous ring of steel were magnetized it would show no external magnetic action: such a ring would manifest opposite free poles of equal strength, at any point in which it might be cut across, and part of its energy would pass into the external circuit which would be then developed.

121. ATTRACTION AND REPULSION.—When the magnets approach each other they manifest *attraction* between unlike poles N and S and *repulsion* between like poles N N or S S. When a non-magnetized but magnetic body approaches a magnet it is always attracted, because magnetism is *induced* in it as just described in true polar order. If a weak magnet approaches a strong one, its magnetism may be overpowered by induction either temporarily or permanently. *Repulsion* however, is not due to any repulsive force between the poles; as in the case of electricity p. 57, it is simply the reactions of the whole fields on each other and the endeavour to place themselves symmetrically.

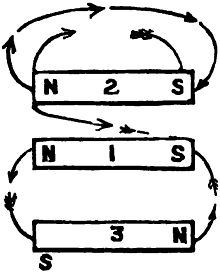
FIG. 39.



Attraction is illustrated in Fig. 39 which shows the action of opposite poles approaching: the lines of the magnet and external fields of 1 and 2 enter each other and blend in one: they draw together just as do opposite electric charges, and the result is that the two magnets constitute one long one, in which the S N poles at the middle disappear, and their forces are tranferred to the external poles, as when two Leyden jars or galvanic cells are coupled in series.

Repulsion is explained by Fig. 40 where 1 and 2 are magnets with like poles presented: at once the lines of 1 S and 2 N coalesce and tend to turn the magnets round, so as to produce the conditions of Fig. 39. If motion is only possible in the vertical line as shown, the magnets will recede from each other because each of them seeks to take possession of the molecules of surrounding air to complete its field, and therefore the magnets themselves move in the direction which involves the least resistance. Fig. 40 shows also another instance of attraction as between 1 and 3 where both poles act together and each bar acts as the external field of the other.

FIG. 40.



122. MECHANICALLY PRODUCED FIELDS.—Fields of force such as are shown in these figures are not merely imaginations: they are capable of being visibly produced by mechanical means, and in them may be reproduced phenomena strongly resembling those of attraction and repulsion. The curious vortex rings formed of smoke issuing from an opening in a chamber subjected to a sharp blow (and resembling those often produced by cannon) are to some extent illustrations of this, for these circling rings possess many of the attributes of solid bodies, moving as a connected whole in space and even rebounding from each other.

Dr. C. A. Bjerknes of Christiania exhibited at the Paris exhibition of 1881 a series of experiments in which the motions of attraction and repulsion were very perfectly imitated by means of currents of water. The apparatus consisted of small drums connected to an air-pump which alternately expands and contracts the diaphragms: to give any intelligible explanation of the interesting experiments would occupy several pages, but the result is that if two such drums are placed in water so that one of them is movable, and a succession of pulsations imparted to the diaphragms, *attraction* occurs if both pulsate alike, but *repulsion* occurs if the pulsations are alternating.

Mr. A. Stroh in a paper read to the Society of Telegraph Engineers, 27th April 1882 (and which received the rare honour of repetition) illustrated the same principles applied to vibrations in air. His paper will be found in vol xi. p. 192 of the Proceedings of the Society and in the *Electrician*, vol. viii. pp. 405 and 421, with numerous illustrations showing the effects produced. These show just such "fields of force" set up by pulsations in the air as are shown by iron filings in the case of magnetism.

123. **Laws of Magnetic Force.**—Many attempts have been made to fix the laws of attractive force of magnets, and the result appears to be that it varies inversely as the square of the distance, as it must indeed from the cause which generates this universal law of actions proceeding from a centre, this being a necessary consequence of the fact that the areas of spheres increase in that ratio: but this only applies to each point of a magnet regarded by itself; practically no distinct law can be laid down, as the force is a compound action: it is not governed merely by the distance of the attracted body from the magnetic poles, but by the form of the acting "field of force" between the poles. It is in fact quite possible to make a number of magnets, all of equal power upon an armature in contact, yet all differing in their attraction for their armature at different distances.

Let us conceive two such magnets: A (N—S) with 1 inch between its poles; B (N————S) with a space of 3 inches. It is evident that the field of A will be the more intense, but that it will extend only a small distance from the ends of the magnet: necessarily therefore the force of attraction on the armature will diminish much more slowly, as distance increases, in the wide magnet B, than in the narrow one A. The real law is to be found, not in the distance of the armature, but on precisely the same principles as govern the relations of two derived inductive circuits, §§ 87 and 91. The magnet has in fact two circuits in which to close its lines of force: a reference to Fig. 29, p. 90 will make this clear; if we consider + and − to be the polar extremities of the horseshoe magnet, the magnetic field is shown by the arrows; it being formed on the same principles as the electric field. If we now imagine a bar of iron approaching from above, this, by its greater magnetic capacity, will draw the lines into itself, and two fresh fields will form between its extremities and + and −. It is evident these two fields are a pair in series, dividing the force with the original field in *the ratio of the several capacities*, which may be roughly considered as represented by the relation of the distance between + and − as against the sum of the distances + armature −; here again it becomes obvious that no law based upon the mere distance of the attracted body without considering the form and conditions of the magnet, can possibly express the facts and forces.

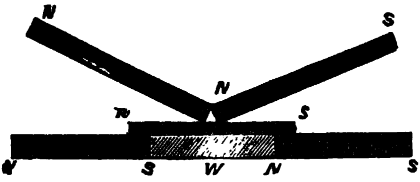
It would seem therefore that it is a mistake to bring the poles of horse-shoe magnets near together; that they would do more work if the opening is wide, because when once in contact the length of the armature offers small resistance, if it be made of pure soft iron, while this form gives greater range of work.

The force exerted by a magnet holding up a weight is measured in dynes by multiplying the weight in grammes by *g* the force of gravity at the place, which is about 9·81 in England.

124. Magnetization.—Steel may have magnetic power developed in it by drawing a bar magnet along its several surfaces, always in one direction; it is still better to arrange a complete system of bars forming an octagon or square, and draw the magnet round and round, always in one direction: in this plan the bars may be all steel, or alternate steel and iron.

If the operator has two bar magnets, an excellent plan is to place them with opposite poles together over the middle of the bar to be magnetized, and then to draw them slowly asunder to the ends, repeating this six or eight times on each face. This process is still more effective if the ends of the bar rest on two other magnetic bars with their opposed poles in the same direction as the moving magnets. Fig. 41 shows this process, N S being the bar to be magnetized and W a piece of wood to support it and steady the lower magnets. This is called the method of single touch, and is best suited to thin needles and bars not more than a quarter-inch in thickness.

Fig. 41.



The method of double touch may be illustrated by the same figure.

The triangular space between the two movable magnets is filled with a piece of wood, and their upper ends connected by a bar of soft iron, and both are moved to and fro along the bar N S, without separation. This process gives more magnetic power, but is apt to be irregular and to produce *consequent points*.

Horse-shoes should be magnetized on the same system; closing the poles with a soft iron armature, or a bar magnet properly placed, or two can be arranged facing each other.

The bar magnets may be advantageously replaced by electro-magnets which can be given a much higher specific magnetism than steel can retain; this is a great advantage because the magnet can generate no higher intensity than it possesses itself, and therefore the stronger they are the better they magnetize.

125. THE BATTERY PROCESS.—This is the most convenient. It consists in making the steel bar act as the core of an electro-magnet for a few seconds. A short coil should be made of stout covered wire, the central opening of which is large enough to allow it to be passed over the bar. It should be arranged at the middle of the bar, and connected to a battery sending a powerful current through it, and regularly passed along the length both ways several times, allowing the ends to half enter the helix, and brought back to the middle before the current is stopped; the action is facilitated by slightly tapping the magnet during the process to produce vibration. It is also found that an intermittent or breaking current is more effective than a continuous one.

The magnetizing is also assisted by completing the magnetic circuit externally with soft iron: in this case also the magnetism retained is higher than if the steel is not provided with an armature to complete the magnetic circuit: the reason is that as in compound magnets, part of the lines are apt to return within the mass of the metal.

Further information as to magnetizing will be found in the section upon Galvanometers.

126. QUALITY OF STEEL.—Some authorities say that for large magnets, hardened cast steel is best; for compound horseshoe magnets the same steel annealed at 500°, or hard shear steel; for needles, cast steel annealed in boiling oil. Steel made of the best iron, such as Swedish, makes the best magnets: but it is very doubtful if *cast* steel is adapted to the purpose. It is now found that the presence of about 3 per cent. of tungsten (wolfram) endows steel with high magnetic power; this steel is manufactured at the Allevard works in France, and is now employed for high quality magnets by many makers, but it is rather costly.

Cast iron will also take permanent magnetism; it should be of a quality containing little carbon, known as white iron, and is improved by the addition of 10 per cent. of steel: it should be tempered or rather hardened at a high temperature, and it is not unlikely that the best process would be that known as "chilling," that is casting in cold iron moulds. Attempts have been made to magnetize both cast iron and steel by a current passed while in the act of solidifying, but the result is to produce hollow castings. The moulds may also be placed in a powerful magnetic field, but it is very doubtful if the result would repay the trouble and expense.

By care in selection of metal, and in magnetizing, bar magnets have been produced carrying 20 times their weight, and horse-shoes 40 to 50 times their weight; as to this see §§ 135–6.

127. FORM AND ARRANGEMENT.—For compass needles, the best form is flat, tapering from the middle to the points; for bar and horse-shoe magnets the mass of material should be divided into a number of plates not exceeding a quarter-inch in thickness, separately tempered and magnetized, and arranged with their similar poles together; they should be insulated from each other by sheet brass or cardboard, and bound together by screws or external bands of brass, and in some cases it is well to terminate the whole by pieces of very pure soft iron, shaped as desired, fitted to the end of the bars, and secured to them.

Very powerful magnets have been made of late from very thin steel plates, similar to that used for clock springs, with the ends gathered into terminal blocks as just mentioned. These, which are called "Jamin's" magnets, are much used for small dynamo machines, fuze exploders, and similar apparatus.

When several bars are thus united, the total force is never equal to the sum of the whole separately, because the similar poles tend to neutralize each other; in some cases the central bars will even be reversed by this action, for which reason they should be the longest. This is the reason, together with the superior temper of the metal, and more complete penetration of the magnetism, that a number of separate pieces give more power than a solid bar of the same mass, as in this the interior portions are apt to take reverse magnetism to the exterior, thus completing closed magnetic circuits, and leaving little force to be exerted on external objects.

128. PRESERVATION OF MAGNETS.—They should be carefully handled, and all jarring actions avoided; when not in use needles should be placed in the true magnetic direction; the

same with bars; but either may be still better preserved by placing two together with their poles reversed, and a small piece of soft iron between them at each end. Horse-shoes should always have the keeper or armature on, and their powers may be greatly increased by hanging them up with a weight attached, which can be gradually increased. Care should be taken, however, never to violently detach the keeper, and when this is removed for use, it should be done by sliding it off across the poles, not by pulling it away.

The power of a magnet is influenced by its surroundings, such as neighbouring magnets and currents, and also by temperature: a strong heat demagnetizes steel, and the magnetism even lowers with an ordinary rise of temperature, increasing again as temperature lowers. It is also found that a flash of lightning, even though distant, affects the magnetic force, showing how intimately connected all nature is. M. Marcel Deprez (the construction of whose galvanometers renders the question of constancy important to him) asserts that magnets do not vary in their intensity by lapse of time, and has described some interesting apparatus and experiments in proof of this; but general experience does not agree with him.

129. *The earth itself is a large magnet*, and this is the reason that the magnetic needle has an apparent directive power, because it places itself on the lines of the earth's magnetic field. Terrestrial magnetism is a subject by itself, and one of vast practical interest, but it is out of the scope of the present work. Our concern with it is simply to regard the earth as a huge magnet, and to understand that its actions are the same as those of any other magnet. The poles of the earth's magnetism are not coincident with its axis of revolution, nor are they permanently fixed; hence the *variation of the compass*, which varies according to some definite but as yet unknown law. It appears as if there were two magnetic axes (that is two N and two S poles) which make a slow revolution around each other, while this compound axis also revolves around the polar axis of the earth in a period of about 320 years. At present the position of the magnetic poles is

North pole. Latitude 77° 50′; Longitude 63° 31′ West.
South „ „ 77° 50′; „ 116° 29′ East.

The *variation*, or declination, besides this general change, (about 7′ per year in England and now amounting to 18° 25′ to the westward and diminishing, has annual and daily small variations, due apparently to the electric currents generated in the earth by the variation of temperature.

130. The *intensity or force* is subject to similar variations, caused partly by the change of position of the poles as regards each part of the earth, which at present slowly increases the force in England, and partly by the fluctuations in the causes of magnetism itself, which probably are connected with periodical changes occurring in the sun, and the maximum and minimum periods of sun spots, and also probably with the grouping and relative distances of the planets. Irregular variations accompany displays of aurora, § 141.

The force is considered under two heads.

131. The *dip* or vertical component is the intensity of the attraction with which a perfectly balanced needle is drawn out of the horizontal line with its end dipping towards the nearest magnetic pole, where it would assume the vertical position. The practical effect is that a magnetized needle requires a counterpoise to balance this force, if it is intended to rest in a horizontal plane.

132. The *horizontal intensity* is of the most importance, as in galvanometers the value of a deflection produced by a current is proportional to the horizontal intensity of the earth's pull on the needle at the place of observation, which varies from a maximum at the magnetic equator to nothing at the pole: its position of greatest intensity is in latitude 0°, longitude 101° west, where it equals dyne ·3733. At Greenwich its value was

	Dynes C.G.S.	Metric M.G.S.
1848	·1716	1·716
1873	·1791	1·791
1875	·1794	1·794
1881	·1805	1·805

An approximate formula for ascertaining the value at different parts is given by Biot as $\sqrt{1 + 3 \sin^2 \lambda}$, where λ is the magnetic latitude or inverse angular distance from the magnetic pole.

Another formula is based upon the assumption that the earth is a uniformly magnetized body, or that it acts as the magnetized field generated by a magnet at its centre; the magnetic moment, § 135, gives $\cdot 33092 \times \sin \lambda$.

The measurement of the horizontal intensity at any place requires delicate apparatus and such observations and calculations as are beyond the purpose of this work, and therefore it is better to refer those who desire this information to works going further into the subject of magnetism.

133. The *magnetic field*, consisting of lines of force having *direction* and *intensity*, of necessity varies in force at its different parts; the *unit field* is that which exerts unit force on a magnetic pole: but, as in the mutual reaction of two poles, § 134, this magnet itself is a factor in the force, and $F = m \times H$, where m is the magnet and H the intensity of the field: distance does not enter into the formula because it is already one of the elements which define the intensity. H, which is always used as the symbol of magnetic intensity, is the field produced by the unit pole (Weber) at the distance of one centimetre, and more generally it is as $M \div D^2$, as the strength of the pole and inversely as the square of the distance. It is proposed to call the unit field intensity a Gauss.

134. The *strength of a pole* resembles the unit quantity of electricity, § 72, and a unit pole means *one which at one centimetre distance repels an equal similar pole with a force of one dyne.* It is related to the same formula as is given § 71 and $F = \frac{m \times m'}{D^2}$. In fact it is also called the unit of magnetic quantity, and it is proposed to call it the Weber, a name which, highly proper in itself, will lead to great confusion because it has been, until recently, the name of unit dynamic electric quantity and current. Its value is 10^8 C.G.S. units.

It should be understood that the *pole of a magnet is not a fixed point* in it: it is simply the focus on which the molecular forces combine: therefore this pole or focus will be changed in position by any cause which modifies the field of the magnet, such as the approach of a magnetic substance or another magnet.

135. MAGNETIC MOMENT.—In mechanics the "moment" of a force is its value under given circumstances, as of the force applied to a lever to move it around its fulcrum. A magnet is a lever, its centre the fulcrum, its poles the point at which the force is applied, and therefore the length of leverage. In such cases the action in opposite directions on the two ends of the lever, exerting an effort, not to move it in any direction bodily, but to turn it on its axis, is called a "couple," and the couple tending to turn any magnet placed at right angles to the pull of the field is $m\,l \times H$, where $m\,l$ is the *magnetic moment*, depending on m the strength of the pole, and l the length or distance between the poles. As a consequence of this, and also of the definition of magnetic intensity, if we have two bar magnets of equal dimensions and equal force, we double the "moment" of one by adding the other to it either end to end, as this gives $2\,l\,m$, or by placing them side by side, which gives

$2\,m\,l$: in fact the *magnetic moment of any uniformly magnetized substance is proportional to its volume.*

The moments of magnets may be compared by their relative actions as regards another magnet; if we use the earth as this magnet (and do not need the high accuracy which would take into account the varying magnetic intensity of the earth itself) the moment of a bar magnet may be measured by suspending it by a fibre and counting the time of one oscillation or the number of oscillations in a given time, the relative moments are as the square of the number of oscillations, or inversely as the square of the time of one oscillation.

To obtain the moment in absolute measure a very short needle is freely suspended so as to hang in the magnetic meridian over a zero line. The magnet is placed parallel to this line, at right angles to and in the plane of the needle, at such a distance that it produces a deflection of only a few degrees. Let θ be the angle of deflection, d the distance between the centres of the needles, H the horizontal component of the earth's magnetism, § 132, then $m\,l = \mathrm{H}\,d^3 \tan\theta$.

Horseshoe magnets may be similarly measured if their ends are placed on the line which a bar would occupy, and the distance measured from the central point between them.

Among the examples quoted by Prof. Everett, it is said that Gauss found the magnetic moment of a steel bar magnet weighing 1 lb. (453·6 grammes) to be 10088 C.G.S. units, and that Kolrausch finds that the maximum permanent magnetization retained by steel in very thin rods is such as to represent a capacity of nearly five times this. This gives according to these observers:—

Gauss,	moment per gramme,	22·24.	Intensity,	175	C.G.S.
Kolrausch	„ „	100·00	„	785	„

The magnetic moment of the earth is $\cdot 33092 \times \mathrm{R}^3$ and the earth's radius R being $6 \cdot 37 \times 10^8$ centimetres, this is 855×10^{23} C.G.S. units.

136. The *intensity of a magnet* may be considered as the relation of the force to the mass of matter it is charged on, and therefore varies as the ratio of the magnetic moment to the weight or volume of the magnet; thus, if one bar has a moment equal to that of another of double its weight, it is itself magnetized to twice the intensity. The C.G.S. unit of intensity is that of *a cubic centimetre having unit magnetic moment.* The earth's magnetic intensity is only ·0790 which is about ·000455 of that of Gauss's pound magnet, § 135, and therefore 1 volume

of highly magnetized steel has a capacity equal to 2200 volumes of the earth's mass regarded as a uniformly magnetized body.

137. *Magnetic capacity* would be a suitable name for the maximum intensity which could be imparted to unit volume of any substance. Prof. Rowland gives the value in C.G.S. units :—

Iron and steel	at 12° C. =	1390 ;	at 220° C.	1360.
Nickel	„	494 ;	„	380.
Cobalt	„	800 ?		

But this is a subject requiring examination, because it is very certain that different qualities of iron and steel possess very different capacities as to *reception* of the magnetism imparted by a given or maximum current, and as to the permanent magnetic force it can retain, § 138. Different authorities give values ranging from 400 to 1000 for steel.

138. *Saturation* implies that a magnet is charged to the utmost the capacity of its materials will admit. Under the influence of an electric current, the magnetism will at first grow in the ratio of the current, but after a time the growth of the current produces a diminishing growth of magnetism, till at length a limit is reached at which no additional current will increase the magnetism. Steel reaches this point sooner than soft iron. But when the magnetizing force is suspended, the magnetism is lost to some extent, till an intensity is reached which is tolerably permanent (§ 128). Iron loses the magnetism almost entirely, though a small "residual magnetism" is always retained. The softer and purer the iron the more freely it absorbs and the more completely it gives up the force.

139. *Coercive force* is a name given to this property of resisting and retaining magnetism. If steel were the only substance possessing it we might attribute it to some insulating or polar action due to the carbon: but as nickel and cobalt both possess it as pure metals, all we can say is that we do not know what imparts the quality.

140. *Consequent poles* are similar poles opposed in the bar of metal as (N——SS——N) where we have the apparent anomaly of a magnet with two north poles: such magnets have uses and are largely produced in dynamo machines : but consequent poles destroy the value of ordinary magnets. If a piece of soft iron is applied to the N end of a bar magnet, it is attracted because polarity is induced in it ; it becomes itself a magnet with its S end in contact with the magnet. If, now, a second bar magnet is applied with its S end to the other end of the iron, the action is increased, the iron held with double force ; but if the

N end of this second bar be applied, the two actions neutralize each other, and the iron, though in contact with two magnets, will have only a slight attraction exerted upon it. In this case the armature has consequent poles formed in it and the opposing fields neutralize each other. The same effect is produced if a N pole approaches the end of a piece of iron hanging from a N pole: the iron may fall off. If a S pole were approached, instead of weakening the attraction of the magnet and tending to draw away the iron, the attractive force would be increased.

141. AURORAS.—These are closely connected with the earth's magnetism, although the exact relation is not known. They are not unfrequently attributed to *electric* discharges, similar to those effected in vacuum tubes, occurring in the upper strata of the air. But the aurora is a general, not a local phenomenon, though it may be more strongly displayed at particular parts. There is ample evidence that auroras are manifested in both north and south polar regions at the same time, while we have no reason to suppose that these have opposite electric charges or conditions, and have very much evidence that electric currents circulate around the earth much as though the earth were an electro-magnet; the reverse action is, however, possible, and the currents might be due to changes in the magnetism, It seems more probable that the aurora is really an illumination of the lines of magnetic force: at all events the auroral corona always forms around the position of the magnetic pole, and its lines correspond to those of the magnetic field: there appears also to be some connection between the aurora and *parhelia* or mock suns, which are due to a peculiar arrangement of ice particles in the upper air: this renders it probable that the play of light and colour, and the shifting streamers of the aurora are due to the magnetic lines of force affecting the constantly varying strata of moisture floating in the air.

Prof. Lendstroem of Helsingfors has, it is said, recently produced natural auroras by artificial means; he raised a number of points on the summit of two hills, one of them 3600 feet high, in 67° N. lat., connecting these points to earth at the foot of the hill: an aurora was formed rising 300 feet in the air and exhibiting the true auroral spectrum. This result, due to lines of atmospheric electric discharge, is probable, because the aurora does strongly resemble some forms of electric discharge: but this would not diminish the probability that the true aurora is a luminous effect of magnetism rather than of true electric discharge.

142. MAGNETIC STORMS.—These are the constant accompaniments of the aurora, but often occur when there is no visible

aurora; they have been observed to accompany changes in the sun, sudden outbursts of the hydrogen prominences and development of sun-spots. No doubt they influence health and weather, but they have no necessary or obvious relation to these. They consist in the development of strong but fluctuating currents in the earth, which frequently rise to a force of 200 Daniell cells and occasionally to 2000. The direction is usually from east to west as though the positive current followed the sun. Telegraph lines running east or west become useless, except by connecting two together to form a complete circuit independent of the earth; but lines running north and south are comparatively unaffected.

On 17th and 18th November, 1882, a severe magnetic storm affected the whole earth, and suspended telegraphic communication in great degree. It was accompanied with a brilliant aurora; there were also heavy snowstorms in many places, and at the same period there were several large sun-spots forming in the sun. Paragraphs went the round of the papers saying that "by means of the storm alone, electric lights requiring 8 horse-power were kept burning some time." This, however, resolved itself into the fact that an 8-candle Edison lamp had been illuminated. During this storm the earth's magnetism underwent rapid fluctuations, and the declination varied 1° 18′, and the dip half a degree: simultaneous changes were observed in Europe, America, and Japan.

143. DIAMAGNETISM.—By means of electrical currents and helices, magnetic effects can be developed in all substances, and Faraday and others, by means of very powerful magnets, have proved that magnetic actions do thus occur, modified by the nature of the substances and their molecular arrangement, which lead to a classification of substances as magnetic and diamagnetic.

The first class when interposed between the poles of a magnet, place themselves with their longer axis in the line joining the poles; the latter arrange themselves across that line. There has been a tendency among some philosophers to attribute this to a force distinct from magnetism, but there seems no sufficient reason for it, as the properties of the magnetic field will explain the facts; it would seem more probable that the diamagnetic substances are those in which the faculty of assuming the magnetic condition is feebler than in air, and that therefore the molecules of air form the field more readily than those of say bismuth, and consequently move these latter into the position in which they take up the least portion of the lines of force; thus a tube containing a weak iron solution will be magnetic in air, but suspended in a vessel containing a stronger solution of iron it acts as a diamagnetic substance. Diamagnetism will not be further entered upon in this work. See § 117.

144. Before leaving the subject of magnetism, it will be well to point out the error of the common conception of magnets as inexhaustible sources of force. It is this misconception which has led so many to waste their time in trying to devise perpetual-motion machines, of which magnetism was to supply the motive power. It has also given rise to many questions as to how it is that a magnet can impart force to any number of other magnets without itself parting with any force.

Magnets, like springs, can only exert the power which has been put into them: *they have no force of their own.* In the act of magnetizing, whether by magnets or by electricity, a certain amount of energy is charged upon the molecules just as it would if each of the molecules in Fig. 33, p. 94, were a spring which was wound up in the act of magnetizing. When the magnet exerts any force, *it parts with that force;* it is to that extent exhausted, and the energy it parts with is distributed over the new "field," or in the armature, &c., which has been moved. If the armature is a mass of iron as large and heavy as the magnet can hold, the magnet is exhausted; it will no longer affect external magnets, &c., or but very slightly. Before the magnet can exert any further force, the requisite energy must be restored to its molecules. This is done by removing the armature, which requires an exertion of force equal to that exerted by the magnet in attracting it.

The distinction is simple, but important; the common idea regards the removal of the armature as an exertion of force against the power of the magnet, and in some sense this is so. But the real action is the restoring to the magnet the force which it has given up to its armature, which is effected by the molecules themselves so long as they retain the magnetic condition.

So in the act of magnetizing, it is not the magnet which gives the force, but the energy expended in the act, just as in cutting a piece of iron with a steel chisel it is not a force in the chisel which does the work. The magnet and the chisel have each certain molecular properties which enable external energy to produce the desired effect: in the one case of effecting a molecular arrangement in the steel bar; in the other of destroying the molecular arrangement and cohesion of a piece of iron.

CHAPTER IV.

GALVANIC BATTERIES.

145. It is difficult to examine the facts of galvanism thoroughly in any progressive order. It appears best to commence with examining practically the various sources of the force, the different forms of battery; but this can only be done by the aid of knowledge of a much higher order. Students, therefore, must at first assume the principles and laws necessary to understand the facts, and return to these again after the study of those principles of measurement, &c., based upon the facts.

If we place a piece of ordinary sheet zinc in a dilute acid, we find that a tumultuous action takes place, the zinc is dissolved, and hydrogen gas is given off. Another effect is produced which is seldom set forth when this fundamental experiment is stated; as the zinc dissolves, the liquid becomes heated. Now this last fact is the one of primary importance; for with all the similar facts in chemistry, it teaches us that whenever an action takes place spontaneously between substances, energy is set free, usually as heat. Let us examine, though only cursorily, what occurs in this instance, and why it occurs. The full explanation will be found in Chapter VIII.

The old explanation, and one even now frequently given, is that the zinc decomposes water, H_2O, gives off the hydrogen, and forms oxide of zinc, ZnO, which is then dissolved by the acid, forming a salt of zinc. The true explanation is far more simple; the acids are substances in which hydrogen forms the base, united with a special acid radical; hydrogen, though a gas, has many chemical analogies with the metals, and indeed, there is good reason to believe that it is a true metal, and capable of assuming the solid metallic state in alloy with some other metals, being then a conductor of electricity, and displaying the ordinary physical characteristics of metals. At all events, metals are capable of taking its place in compounds; and thus in the case under consideration, say of zinc acting on dilute sulphuric acid, the metal merely displaces the hydrogen and converts the sulphate of hydrogen, H_2SO_4, into $ZnSO_4$, sulphate of zinc.

146. It is requisite to clearly understand that, besides the material elements, *energy* enters into the constitution of all bodies; all possess a specific quantity of what we know as heat. and according to the molecular theory, the atoms of which all substances are composed are in a constant state of internal motion; the amount of that motion governing the physical state, as solid, liquid, or gaseous, and also the chemical relations; even affinity is probably a function of these motions and dependent upon the wave-lengths of the vibrations proper to each element, as shown by the spectroscope; the less the motions the nearer the atoms approach, and the greater the attraction they exert on each other. Hence when what are called *higher affinities* come into action, the internal motions are diminished; but, as a consequence, this motion becomes external, active and sensible, instead of internal or latent; and thus it is that every act of chemical combination sets energy free in some form, usually as heat, while every act of chemical decomposition requires the supply of energy to re-establish the internal motions, or latent forces, or, as it is usually expressed, to overcome the chemical affinities.

147. Thus, when zinc is dissolving it gives off hydrogen and *heat* while forming the more satisfied compound, sulphate of zinc. If we use a piece of iron it does the same, though more slowly, but if we use copper no such action occurs. If we place in the same sulphuric acid, copper and zinc separate from each other, we see gas pouring off the zinc and not from the copper; but if we permit them to touch, a new phenomenon occurs: the gas appears to issue abundantly from the copper. Still if we examine the liquid we find that no copper is dissolving, while the zinc is dissolving faster than before. Instead of allowing the two metals to touch within the liquid, we connect them by a wire, and we find that this wire is suddenly endowed with extraordinary properties: if it approaches a magnetic needle the earth's directive power is superseded, and the needle no longer points N. and S., but tends to place itself across the wire, and in different directions, according as it is above or below; if the wire be coiled round a piece of iron it endows it with powerful magnetic properties; if the wire be cut in two, and its ends dipped in liquids, it produces chemical changes in many of these; lastly, the wire itself becomes hot. But in proportion as these effects are developed, so does the dissolving zinc generate less and less heat in the liquid. Here we have the explanation of the sources of these external actions; there is no creation of energy; nothing new occurs, except that under the new conditions, the

energy set free by the combination of the zinc takes that form which we call electricity, instead of the other form we call heat (just as it was seen occurs with friction, § 17), and is capable of manifesting itself by its chemical, magnetic, or calorific effects, thus furnishing the three natural divisions of the study of dynamic electricity.

148. The conditions under which energy takes this form are a development of those pointed out in § 32, but more plainly evidenced. The fundamental condition is a complete circuit of conducting substances; where the electricity is developed by chemical action, part of the circuit must be an electrolyte; that is, a liquid whose molecules will readily assume the condition of polarity, and break up into two distinct parts, giving up energy in the act.

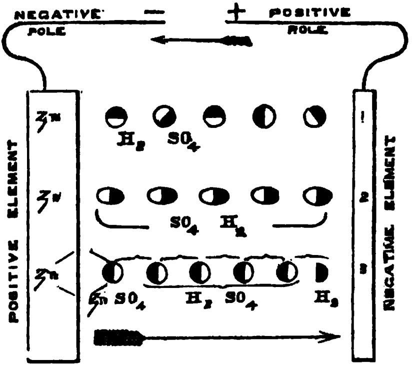
This action occurs under the influence of the zinc, which, as it attracts the sulphuric radical, turns the hydrogen half of the molecule away from itself, and by diminishing the internal attractions of this first molecule, disturbs those of others, if there be this complete chain provided along which the force can act: if not, the hydrogen simply escapes, and the heat is at once set free. The action can be traced by the ordinary chemical symbols. $Zn + H_2SO_4$ must evidently first become $Zn + SO_4H_2$, then $ZnSO_4 + H_2$. The atoms of hydrogen are now what is called *nascent*, and would instantly form a free molecule, taking up and rendering latent that portion of energy necessary to convert them into a gas; but before this process is completed they are in a condition of great activity, and eager for combination; being surrounded only by molecules the nature of which is not changed by the hydrogen (that is hydrogen compounds), the decomposition is simply transmitted along a chain of these: molecule after molecule is decomposed, and the hydrogen is not set free until it reaches a point at which it is powerless to effect a decomposition, and thus in the combination under examination it reaches the copper plate before it becomes free; it does not do so at all if a reducible metallic salt is present at the copper plate, such as sulphate of copper, it then displaces the copper, which fixes itself in turn upon the superficial molecules of the metallic plate, to which the polarizing force is transferred; in fact, that action occurs which absorbs the least amount of energy.

149. These two processes furnish us with a natural division of batteries into: (1) Those in which the hydrogen gas is set free; (2) those in which the hydrogen displaces some other substance; and this latter class consists of two kinds, those in which one liquid fulfils all the requirements, and those

in which two liquids are required, kept apart by a porous partition.

150. Before examining these forms, it will be as well to explain some terms as to which there is apt to be some confusion. As the action commences at the surface of contact of the zinc with the acid, the zinc is called the positive *metal* or element: and hence the order of polarization originated there in the liquid is such that the positive or + ends of the molecules are turned from the zinc, and consequently all the negative ends, which are the acid radicals, are turned towards it. This also corresponds with the terms of static electricity, and shows the wire united to the zinc plate and called its pole, in the same electrical condition as the rubber of a glass electrical machine – or negative. The action passing through the liquid to the copper or other collecting plate polarizes its molecules with their – ends to the liquid, and their + or positive ends towards its wire. Hence we have the zinc, the positive *metal*, *plate*, or *element*, but its wire, the negative or – *pole;* the copper is the negative *plate* or *metal*, but the wire proceeding from it the positive or + *pole.* Fig. 42 shows this,

FIG. 42.



together with one series of the reactions in their successive stages. Line 1 exhibits the arrangement before action, the molecules indifferent, the shaded part representing the + or metallic or basic element or half; the white being the – or acid half. In line 2 we see the molecules polarized under the attraction of the zinc; in line 3 the resulting discharge, the whole chain simultaneously breaking up, one atom of zinc forming a molecule of zinc sulphate; at the other end of the chain, the two atoms of hydrogen which are equivalent to one of zinc, are set free, when they satisfy each other's attractions and together form a molecule of hydrogen gas. Then polarization again takes place, the molecules making a semi-revolution, and resuming the position of line 2. It will be seen that this view of the action involves two actions at each stage, first the semi-revolution of the molecules on their axes; and, secondly, the overcoming the chemical attraction within the molecules; this latter also involves two separate actions; the actual disruption, which occurs only as to one molecule of the chain, and the temporary disruption and reforming of all the other molecules in each chain. These various actions cause the internal resistance of batteries, while the energy given up during the interchange of zinc for hydrogen in sulphuric acid is the source of the electromotive force.

151. That this condition of polarization or strain tending to disruption really does occur is manifest, because although actual disruption can only happen when the whole chain is composed of conducting materials, yet the stress tending to produce it exists exactly as in the cases studied under static electricity. If the two wires are connected to a delicate electroscope, the plates will be found to exhibit electric stress exactly as if they were connected to a machine. This indicates the existence of the complete chain, the air or dielectric between the plates of the condenser being polarized; connect the plates by a conductor, and discharge and current are produced. The liquid under these conditions is in fact acting as a dieletric.

152. In all galvanic generators there are general principles involved which explain the uses and values of each form.

Electrical operations, like mechanical ones, consist of two distinct parts: (1) the generation or collection of energy from some source; (2) the application of that energy to effect the desired purpose, and this latter is divisible into two parts, that is to say, the conveying the energy to its work, in which process it is partially expended, and doing the actual work. Be the work we have to do what it may, one universal law governs all; we must expend in doing it energy equivalent to the work and all the operations incidental to it; under no circumstances will the work do, or help to do, itself; this may seem a mere truism, yet the want of understanding it costs this country many thousands every year. Economy, that is true practical working, consists in obtaining the necessary energy at the lowest cost, and in avoiding all loss in applying it when obtained.

Thus, in ordinary mechanics, it is necessary to select the cheapest fuel, the best furnaces and boilers, then to avoid loss of heat in the steam-pipes, or undue friction in the engine and connected machinery: at every stage there is room for a wise understanding of principles, and a due application of them. Electrical operations are perfectly analogous and require similar attention. The battery or other motor represents the boiler with its fuel, the conducting wires replace the steam-pipes, and the work to be done and apparatus for doing it are the analogue of the engine and the machinery it may drive; while the steam itself, with its capacity for bearing pressure, and thus conveying the energy derived from the combustion of the fuel, strongly resembles the electric "current," with the various tensions which set it up and give it power.

153. We are thus led to the three fundamental expressions employed in the laws of electricity known as Ohm's formulæ, viz. electromotive force, resistance, and current. It is upon a clear understanding of these, in a perfectly definite form, in place of the confusion of the old vague terms "quantity and intensity," that sound and economical working must be based. The full explanation of these terms must be studied in the chapters devoted to each of them; but a slight definition is given (§§ 168–170) sufficient for present purposes.

154. In practical operations we weigh and measure substances as to their gross quantities by pounds and pints; but for present purposes, if any real knowledge is desired, we must dismiss pounds from our consideration, because we must go to nature for our knowledge, and nature employs no pound weights in her operations; she uses only atoms, molecules, and equivalents, as defined §§ 4–11, to which definitions we must now add individual exactness, that is to say, we must consider the quantity of matter which nature puts into each of her atoms, that is, the atomic weight and the valency (§ 6) of the atoms of each element; for the relation of electricity to matter, its passage through, and its effects upon, various substances are absolutely linked to, and wholly dependent upon, the atomic weights of the various substances, upon the valency of the atoms, and upon the consequent construction of the molecules of each distinct substance, § 9. This grand truth of nature is completely obscured by the usual mathematical treatment of the subject.

155. Gravitation acts upon matter according to its mere mass without relation to its nature; or, more truly, weight, our measure of the quantity of matter, is an expression of gravitation; but heat, electricity, and all the forces which act within matter, rather than externally, have a selective power; they

act differently on different forms of matter, and upon examination it is found that these forces act, not upon mere masses, but upon the atoms and molecules of which the masses are built up; their actions are related to the atomic weights and the valency of the several atoms. Thus a pound weight of iron would require twice as much heat to raise it to a certain temperature as a pound of silver would, but equal quantities of heat would raise to the same temperature an atom of iron 56 and an atom of silver 108. This relation is called specific heat of substances.

156. But when electricity passes through solutions of these two metals an entirely different condition arises. It would require just twice as much current (or twice the time with equal current) to deposit 56 of iron as it would 108 of silver: the reason is that the 1 atom of iron has two valencies, or stands chemically (in ferrous salts), in place of 2 atoms of hydrogen, while 1 atom of silver is equivalent to 1 of hydrogen. Thus it appears that heat is absorbed by matter in the ratio of its *atomic weight*, while electric current passes throug hmatter in the ratio of its *chemical valency*.

157. But matter has another relation to energy in the form called chemical affinity: in this aspect each order of combination of each kind of atom possesses its own energy, which bears no known relation to any others: this specific energy is a matter for experiment in each case; but the energy given up in the act of combining (which may be measured either as heat or as electric action) bears an exact relation to what is called the affinity of the atoms forming that combination; to break it up we must apply a force equal to that affinity, and this fact means simply the law already mentioned, that in order to separate the atoms we must give back to them exactly the energy they parted with when uniting. Here also we meet the distinction between "quantity and intensity," or current and electromotive force. The same current would release from combination an equivalent of hydrogen 1 grain, or an equivalent of copper 31·75 grains; but the E M F needed would be very different, and would depend upon the nature of combination broken up.

158. We must now conceive of substances as consisting of molecules built up of two parts, which are called *radicals* in chemistry and *ions* in Faraday's electrical nomenclature. There are many substances containing several radicals, but we are not concerned with them electrically, as only those substances which can form or break up into two radicals are electrolytes, or give this kind of passage to electric currents. These radicals may be similar atoms, as in metals, or they may be dissimilar atoms or radicals, as in salts: all that is to be attended to at present is the

type or skeleton of matter as related to electricity, and the giving to this such a definite form as shall enable the actions *to* be understood. These two constituent radicals are variously named, as—

+	−
Electro-positive	Electro-negative
Basylous	Chlorous
Cation	Anion
Basic	Acid

such as—

Hydrogen	Chlorine
Metals	Sulphuric radical.

Some substances act as either radical, according to what they are united with, but in the electric circuit the radicals belonging to the first column turn towards the negative face or plate, and the second column towards the positive face or plate.

The two radicals are held together in a twofold manner :—

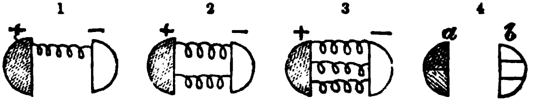
(1) By the valency of the radicals themselves: § 6. This constitutes the several classes of monobasic, bibasic acids, &c.

(2) By the specific energy of the individual substance.

Each of these bonds has a distinct electrical relation. The first governs what is called "quantity," and its actions; it constitutes what has been called the "equivalent of electricity." The second governs the E M F generated, or necessary to enable the current to pass when decomposition has to be effected, and is the basis of the old ideas of intensity. A purely mechanical representation will fix these ideas, but it must be remembered that this alone is its object, not to give a material conception of actual molecules.

Let us, then, typify the molecules as consisting of two parts held together by spiral springs; the *number* of the springs corresponding to the valency of the radicals, and the *strength* of the springs corresponding to the specific energy of the particular compound. We shall thus get :—

Fig. 43.



But either the one or other of these single radicals may be replaced by separate atoms of single valency corresponding to one of Fig. 43, 2 or 3, as shown in 4. Thus Type 1 represents the union of single monad atoms, such as metallic silver Ag.Ag., hydrochloric acid HCl, common salt NaCl. Type 2 represents metallic copper, zinc, &c., and sulphates of those metals, $CuSO_4$, $ZnSO_4$. By regarding the + radical as composed of two distinct monads, as in 4 *a*, it represents the sulphate of sodium Na_2SO_4, sulphuric acid H_2SO_4, and corresponding substances; or by regarding the – radical as similarly divided, it includes the chlorides and nitrates of dyad metals, as zinc chloride $ZnCl_2$. The same applies to all the other classes.

159. The atomic weights are purely relative; they apply to proportions only, whether grains or tons; but if we give them a fixed meaning these molecular types give us the most perfect possible unit of electric quantity and current. Let us consider the weight as taken in grains; then taking hydrogen 1 grain and 1 valency as our base, we have the unit of quantity as that necessary to set free from combination 1 grain weight of hydrogen or 1 atom of any monad, or to do equivalent work in any other atom; thus iron 56 grains, or zinc 65·2, would require two units of quantity to set them free, or would furnish two units themselves while dissolving. To convert this into "current," time has to be taken into account, and for convenience of calculation I take ten hours. Then we measure electric currents by 1 grain of hydrogen, or equivalent action in ten hours. This unit, from its source I call a "*chemic*," and throughout this work this is what is meant by a unit of current, while the term unit of any substance means the quantity equivalent to this current as shown Col. vi. of Table XIII. for elements, and more generally in Col. v. Table V. § 251. The convenience and importance of these units will be seen in the facilities they give for estimating the work and cost of batteries.

160. The galvanic cell must be regarded for some reasons simply as a section of the conductor conveying the current; and, as the first law of the circuit is that the "quantity," "current," or equivalent electric action is equal at every part of the circuit, the battery obeys this law. In each cell an electric equivalent of zinc is dissolved by an equivalent of acid for every equivalent of metal deposited, or other work done which requires a "quantity" equal to that of one unit or chemic current, no matter whether the action be fast or slow. "Quantity," then, means merely the equivalent of chemical action—the passage of energy along one of the chains of affinity, § 158. By this means we can calculate the cost of every kind of chemical or other work, knowing the rate of current to be maintained, and ascertaining the electromotive force needed to maintain it under the given conditions. For this purpose I

have drawn up Table V., § 251, which is used in the calculations relative to the different cells.

161. The E M F generated by a chemical action depending on the degree of the affinity at work in that action, that generating substance is best which has the greatest attraction for the radical of the acid, but practical considerations limit us to iron and zinc as the cheapest; both, however, have the drawback that they maintain their action whether we want the force they can give us or no; pure zinc is, however, very slightly acted on, except when the conducting circuit is closed, while ordinary zinc is continuously dissolved. The reason of this difference is by no means clearly known, though it is usually attributed to the presence of foreign metals setting up little local circuits: and, therefore, this waste action, which contributes nothing towards the generation of current, is called "local action." It has been discovered that common zinc, when amalgamated with mercury, is not much acted on, and this seems to render this explanation somewhat doubtful. However, a well-amalgamated plate is scarcely acted on in dilute sulphuric acid, but the presence of nitric acid, or metallic salts, does away with the protection, which appears to depend chiefly on the adhesion of a film of hydrogen gas to the surface, which prevents contact with the liquid. When the circuit is closed the hydrogen is transferred to the negative plate, and the protection is removed, while the conditions of discharge bring fresh actions into play. Amalgamation also renders the zinc a better source of electricity, as it is more positive than ordinary metal. Zinc should always be well amalgamated for use in cells with acids; but it is of less consequence in presence of saline solutions.

162. **Amalgamation.**—Care should be taken to use only pure mercury; much of that sold contains lead and tin, which are mischievous. The mercury should be kept for some time in a bottle, with dilute nitric acid over it, and occasionally shaken up. To amalgamate zinc, wash it first with strong soda, to remove grease; then dip it in a vessel of water containing one-tenth of sulphuric acid, and as soon as strong action takes place transfer it to a dish (such as a soup-plate); pour mercury over it, and rub it well till a bright silver-like film forms; then set it up to drain on edge, and before use rub off any globules which are set free. Whenever the zinc shows a grey granular surface (or rather before this) brush it well and reamalgamate, remembering that saving of mercury is no economy, and free use of it no waste—for it may all be recovered with a little care. Keep a convenient sized jar or vessel solely for washing zincs

in, and brush into this the dirty grey powder which forms and is an amalgam of mercury with zinc, lead, tin, &c., and forms roughnesses which reduce the protection of amalgamation. This washing should be done whenever a plate is removed, and never less than once a day if in regular use; the fibre brushes sold at 3*d.* and 4*d.* as coarse nail-brushes are excellent for these purposes, but of course must not be left soaking with acids. Let the powder collect for a time and then transfer it to a bottle, in which wash it with sulphuric acid first, and then with dilute nitric acid, and you will recover the mercury; or the dried powder may be mixed with a little salt and distilled over from an iron retort into water.

163. Rolled zinc should always be used in preference to cast. The latter is very hard to amalgamate, and has less electromotive power, but for rods for use in porous jars, and particularly with saline solutions, cast zinc is very commonly used. In this case, great care should be taken to use good zinc cuttings, removing any parts with solder on them, and using a little nitre as a flux, which will remove a portion of the foreign metals.

Rolled sheet zinc, from one-sixteenth to a quarter-inch thick, suitable for cylinders and plates, costs about 4*d.* per pound. The simplest way to cut it to size is to scratch a groove with a steel point, such as a bradawl; run first acid solution, and then mercury along this groove, and allow it to penetrate; then repeat the process on the other side, when the metal is easily broken: it may also be cut with a handsaw. Zinc possesses a peculiar property of softening with a moderate heat, so that hard and brittle as the metal is, it can easily be bent up into small cylinders, if held in front of a good fire till too hot to handle with the naked hand, and then bent round a piece of wood or metal.

164. SULPHURIC ACID.—This is the most important excitant used in ordinary batteries. Real O.V. oil of vitriol has a specific gravity of 1·845, and contains about 99 per cent. of the true acid (H_2SO_4); it is of a clear colour, and has an oily appearance: this is the acid always meant when sulphuric acid is spoken of. Brown oil of vitriol is the ordinary product of the chambers, or this boiled down in lead pans, and contains variable quantities of acid. This is a question of price only, but this acid often contains impurities of serious consequence.

Brown colour may be due to dissolved organic matter, straw, &c., and is of no moment.

Arsenic is often present, and must be strictly avoided, as it unites with the hydrogen given off, forming a deadly poison when strong, and being in any case injurious to health. It is detected by diluting the acid, and passing a stream of sulphuretted hydrogen: arsenic forms a yellow precipitate.

Lead is often present as sulphate, and must be carefully removed, or it will deposit on the negative metal; it is only necessary to dilute the acid in a separate vessel, allow it to cool, and filter it off before use.

Nitrous acid is often present and wastes the zinc by destroying the hydrogen film, but is otherwise of no consequence.

The addition of a half per cent. of colza or other oil to the acid before dilution, shaking well together, precipitates the metals as soaps and forms a sulpho-glyceric acid which is said to protect the amalgamation.

The strength of acid used in batteries may vary from one-twentieth to one-tenth by measure of acid to water.

TABLE II.—SPECIFIC GRAVITY OF SULPHURIC ACID.

One-twentieth, volumes	1·055	70 per cent.	1·598
One-tenth „	1·100	80 „	1·708
One-third „	1·259	90 „	1·807
50 per cent. weight	1·388	100 „	1·846
60 „ „	1·486		

The third line is that strength which has least resistance, and may be used in voltameters. Very strong acid cannot be used in batteries, as there must be at least water enough to dissolve the sulphate of zinc as formed. A good solution is made by mixing 1 part by bulk with 10 of water, which should be soft, as water containing lime is apt to form a deposit on the metal surfaces; if hard, it should be boiled before use. 100 grains by measure of such a solution will dissolve about 11¼ grains of commercial zinc; but it is bad economy to nearly saturate the acid, particularly if several cells are combined in series, as zinc is apt to be deposited on the lower part of the negative plate, which is thus destroyed for the time, and from which, as the zinc is pure, it is a troublesome process to dissolve it. But allowing for impurity in zinc, local action, and a due proportion, or about one-fifth of free acid left, one pint of this solution would dissolve about 1¾ oz. of zinc. We may thus calculate the work a cell is capable of doing as about equal for each pint of solution to 24 equivalents or units, and the cost per unit of the single acid cells (line 27 Table V.) ·0438 of a penny, taking amalgamated zinc at 6*d*. per lb.

165. HYDROCHLORIC ACID.—This will serve equally as well as sulphuric, but is seldom used because it is dearer; it also

evaporates and gives off injurious fumes. It has advantages also, because the chloride of zinc formed will not crystallize and the solution can be more closely worked out. The common acid is generally contaminated with a little iron. See §§ 206 and 211.

166. As a general rule cells are used which are too small, and little regard is paid in proportioning them to their work; this is no doubt due chiefly to a want of consideration of cause and effect, and to the work being seldom regarded as a definite quantity. It is impossible for a small cell to work regularly, because the liquid rapidly changes its nature. In double liquid cells care should be taken that the two are so proportioned as to contain the relative quantities of the two liquids required for the work to be done, so that neither is wasted; and Table V. will show what these quantities are. In some cases, for practical reasons, it is best for the elements to be in the form of plates, but in many cells they are cylinders; and then the question arises, which should be the outer one, the zinc or the negative? This question may be put in another form: if the plates differ in size, which should be the largest? There are two good reasons why the negative metals should be largest. (1) The zinc is subject to local action, or waste, which contributes nothing to the work, and therefore its size should be reduced to just that amount which is requisite to maintain the current required. (2) The negative plate is subject to "polarization" or deposit of hydrogen upon it, and should therefore be as large as possible, § 168. After a great many trials, I have come to the conclusion that the best arrangement is one in which the negative element is a cylinder fixed within the containing vessel, in the middle of which the zinc can be suspended.

167. Among the various forms of battery known, that one should be selected which best suits the work required to be done, for none is perfect or equally fit for all work. A perfect cell would be one which would contain a large quantity of material in small space; would generate high electromotive force; would not alter its properties during work; would have small internal resistance; and would act chemically only while its electric circuit is closed. These qualities resolve themselves into *capacity for work* and *constancy.*

Capacity for work depends on two conditions: (1) the amount of active materials contained in the cells, to which is related "quantity" or "current"; (2) the amount of energy liberated by the equivalent action, § 158, on which depends the electromotive force.

The first of these conditions is controlled by the size of the cells themselves, § 166, and by the solubility of the materials employed or generated by the action. Each equivalent of material, that is of all the substances taking part in the action, will generate 1 unit of electric quantity, or maintain 1 chemic of current, provided it is not wasted by local actions. The second condition calls for a sketch of the terms necessary to understand the subject.

168. *Electromotive force*, shortly written E M F and symbolized by E in formulæ, measures the generative power in terms of potential, § 78, p. 61, that is of the capacity to generate current, or of the capacity to overcome resistance. It depends entirely upon the "intrinsic energy" set free by each equivalent acting chemically, and then charged upon the chain of equivalents in which this action occurs. Therefore *it is entirely independent of the size of the plates or cells.* A simple experiment will fix this in the mind. Take a piece of copper and cut a piece of several square inches, and also a strip like a thin wire; do the same with a piece of sheet zinc; attach the coppers and zincs to wires and wrap the zincs, after amalgamating them, in several folds of blotting paper. Connect the wires to the terminals of a galvanometer and dip the large pair into a vessel of dilute acid; a deflection will occur, *which will rapidly diminish*: attach the small pair and note how much smaller the deflection, which also will diminish even more quickly. Here we have different quantities or currents arising from the same chemical action, because the larger surfaces enable a greater *number* of equivalent actions to occur: this is commonly called a difference of *internal resistance.* The diminution of the deflection is due to what is miscalled "polarization," that is to say to the coating of the copper plate with hydrogen or hydride of copper, which generates an opposing E M F and so reduces the active force available to produce current. Now dip the plates into a strong solution of sulphate of copper: the deflections will be proportionally affected as before by the size, but (1) they will both be greater, and (2) they will remain steady. The E M F *is greater in this case* by exactly the difference in the energy absorbed from the chemical action by the setting free of hydrogen or copper, § 148. Also as the copper plate is not altered by the coating of copper, as it is by that of hydrogen, there is no "polarization" or counter E M F generated.

Now join together the wires from the two coppers, connect those from the zincs to the galvanometer, and place the plates in sulphate of copper as before; *no deflection whatever will be seen.* The two actions are opposed: that on the small plates acts as a counter E M F to that on the large plates, and the stress each can set upon the circuit being equal, no current is generated: the condition is something like "consequent poles" in magnetism, § 140, or the hydrostatic paradox, in which a large body of water in, say an open cask, is balanced by a column of equal height in a small tube connected to it.

If now one pair of plates is washed and placed in the acid while the other remains in the sulphate of copper they no longer balance, but a deflection will be obtained corresponding to the difference of the two first, that is to say, due to the difference of the two forces. The two pairs will not balance each other if both are placed in acid, because although they generate equal E M F at the zincs, the different areas of the coppers will result in a stronger polarization or counter E M F at the smaller plate: this may not be shown in balancing where no current is produced, but tells powerfully in actual work.

The unit E M F is called the volt, and is a little less than the force of a Daniell cell, which is volt 1·079.

169. *Resistance*, symbolized by R, is an expression of the conditions of the circuit, its capacity to transmit current, and the work expended in doing so. It is to be considered in two portions: (1) *internal*, due to size of plates, conducting power of solutions and porous cells; (2) *external*, due to the nature of the material of the conductor, and the work doing. Work is best done when these two are equal. But internal resistance is comparable to engine friction, it is waste: therefore the greater the external resistance compared to the internal the less the expense.

The unit of resistance is the ohm, and may be conceived as represented by a wire of pure copper ·01 inch diameter, 10 feet long, and weighing 2 grains per foot.

170. *Current* measures the electrical action at any section of the circuit: it is best represented by its chemical effects as shown in a voltameter, and is exhibited at any moment by its definite magnetic action as shown in a galvanometer. Its symbol is C and its unit the ampere.

But at this stage another unit, based purely on the equivalent relations of matter and electricity, will convey the facts more clearly to the mind of the student. This is the *chemic* explained § 159, a current capable of doing 1 unit or equivalent of chemical work in grains per 10 hours.

171. E M F, resistance, and current are so related that current is proportional to E M F and inversely proportional to resistance. That is to say, if in a given circuit we double the E M F, the current will be doubled: if we double the resistance, as by

adding wire, the current will be halved. But we should not double the current, by doubling the number of cells in series, though that would double the E M F. In such a case we should also have increased the resistance by the internal resistance of the added cells: if the external resistance were small, the current would scarcely be altered, because it is the total resistance of the circuit which is to be considered, and when the external resistance is small, this resistance is nearly all internal.

Electromotive force is gained by using cells of greater force or by connecting cells in "series," that is + –, + –, which also adds their resistances, and the E M F of a circuit is the sum of all forces thus added, which may be those of various kinds of cells.

Internal resistance is reduced by using plates of large size or by coupling cells together + + and – –, and then to the circuit so as to act as one cell: different kinds of cells must never be coupled in this manner.

172. *Constancy* means, that having once set up a battery under certain circumstances, giving a certain current, then that current shall be steadily maintained till the materials of the battery are exhausted. Of course, the conditions assume that the external resistance remains unchanged; therefore, inconstancy, or fluctuation of current, may arise from variation in either the force generated, or in the internal resistance of the battery. The latter change occurs to some extent in all cells from the formation of sulphate of zinc, and the former occurs in most in consequence of so called "polarization," § 168.

A battery which would at all times, and under all variations of external work, generate a uniform electromotive force would be invaluable; but none such exist. The Daniell, § 187, is the nearest approach to it, and the Grove, § 204, the next.

Duration is quite distinct from constancy; it depends entirely on the cell containing materials enough to continue working the required period; this is therefore a function mainly of size of cell, as related to the required work, as is explained § 167.

Density of current.—This means the quantities of current related to the surface area of a conductor, such as the plates of a cell. Theoretically, current is proportional to E M F, but every reaction has a particular rate beyond which it cannot be pressed without introducing new conditions. Thus the rate at which zinc can be consumed in acid will depend upon the strength of the acid, and the deposit of copper can only proceed at such a rate as the diffusion of the liquid will bring fresh copper salt to replace that which is reduced: so with every action there is a maximum rate of proper working, and if an external EMF presses the action beyond this point, a counter EMF and increased internal resistance result. The consequence of this is that no cell can advantageously form part of a circuit transmitting a larger current than the cell would itself generate on *short circuit*, that is with no external circuit, and that the most advantageous current a cell can be called upon to produce is half of its short circuit power. Another consequence is that small cells should not be put in series with large ones except for passing currents adapted to the smallest size.

173. The simplest form of galvanic generator, and the one first devised, is the combination of alternate plates of copper and zinc. Most electrical works employ a good deal of space, and many figures, in describing the various forms devised by way of improvement, by Cruikshank, Wollaston, and others, consisting chiefly of the mode of arrangement in the containing vessels, the use of double copper plates surrounding the zinc, and such like matters; the value of which has been entirely destroyed by further process. But, as the simple copper-zinc arrangement is the most unsatisfactory form known, it is wasting time and space to describe such modifications; this couple calls for attention simply for the sake of principles.

COPPER AND ZINC.—When the plates are first immersed in dilute sulphuric acid, and the wires connected to a galvanometer, a considerable deflection is produced, marking a powerful current, but even in a few minutes the effect rapidly decreases, § 168. After a short time the copper is seen to be covered by a film, which is commonly said to be oxide of copper, and the other metals contained in it. This is erroneous, however, for oxides could not possibly form in the presence of nascent hydrogen; it is really a combination of this hydrogen with the metal, and the diminishing power of the cell is due to the formation of this hydride or alloy, which prevents contact of the copper with the liquid, thereby increasing the internal resistance, while the affinity of the hydrogen for the acid radical resists the polarizing power of the zinc and therefore diminishes the electromotive force of the couple or cell.

Pure copper, as deposited by the electrotype process, has a higher power, probably because of its purity, but also on account of the nature of its surface, which is covered with innumerable fine points, from which the hydrogen is given off more readily than from a smooth surface. Hence, if a copper negative plate is to be used, it should have a deposit of copper formed on it. The rapid failure of power will be observed in Table IV. p. 168.

174. **Iron and Zinc.**—Iron has often been recommended as a negative element because its surface keeps clean. Its force is very low as may be seen by the table of experiments, p. 168. The reason of its surface remaining clean is mainly that the acid acts upon it as well as on the zinc, and thus causes much waste.

175. **Silver Negative.**—This acts very well, especially if a thickish deposit is formed upon a thin sheet, so as to obtain a rough surface. Such a coating may be deposited on copper, but deposited metal is always porous, and the acid is always found to act upon the copper; this is the only drawback to a plan often suggested, of making negatives of copper-wire gauze plated, which otherwise makes an excellent negative; it should never be left in the acid when out of action.

176. **Platinized Silver.**—Smee having assured himself that the nature of the surface was of the greatest importance, and that the hydrogen is more readily given off from a rough surface than a smooth one, and also bearing in mind that platinum has the highest electromotive force of all the metals as opposed to zinc, deposited this metal as a fine black powder on the surface of silver, and the cell with this as the negative plate, which justly bears his name, is one of the most valuable gifts ever made to electrical science. But even this cell rapidly fails in power, if worked with a full current, as may be seen Table IV. p. 168. In its usual form the Smee battery is of simple construction; the silver sheet is held in a saw-cut down the middle of the inside surfaces of a wooden frame, of which the top and bottom bars may be $\frac{3}{4}$ inch thick, and the sides $\frac{3}{8}$, the wood being well baked and soaked in melted paraffin before putting together by the usual mortises and tenons; a sheet of zinc is held on each face by means of a brass clamp with a screw, which presses them against the frame, and carries also the binding-screw for the connection, that for the silver passing through a hole in the top bar, and being soldered to the silver; the zincs should be narrower than the silver, in order to give free escape for the gas. For large works the sheet is frequently fixed upon a board, so as to use one side only, and is placed outside the zinc.

177. An excellent mode of making connection to the zincs in a large cell is to have a narrow trough containing mercury across the bottom of the cell, connected by means of a wire covered with acid-proof cement, § 188, so that merely standing the plate in the trough connects the zinc at once, and also keeps up its amalgamation; a bar should be provided in the upper part of the cell for the zinc to lean against. Each zinc, for regular working, should be in the form of at least two plates;

one of them can then be removed and replaced by a fresh plate without deranging the work going on.

178. Substitutes for silver have often been proposed, as copper, lead, and an alloy of lead, tin, and antimony; they are all bad economy, considering that they give lower EMF and that silver has an intrinsic value of its own, even when worn out. Rolled silver can be obtained ready platinized, or ordinary thin sheet can be lightly roughed with fine glass-paper, or by dipping in nitric acid, well washed and platinized. Insert in a vessel with dilute acid, and connect it by a wire to a small slip of zinc in a porous vessel in the same acid; in fact, mount it as a battery, but exposing at first only a mere touch of the zinc to the liquid; drop in a few drops of platinic chloride, and stir; gradually a faint colour forms on the silver; add more platinum salt, and increase the zinc surface; and after a good adherent coat is formed, gradually increase the action till the surface is fairly covered with a black coating, which touch as little as possible. The platinum solution is made by dissolving scraps of thin platinum in a mixture of two parts of hydrochloric and one of nitric acids; the solution is very slow, and is best effected in a flask with a long neck, in which is inserted a test-tube filled with water, and stood by in a warm place.

179. Carbon and Zinc.—Mr. Walker suggested the use of graphite plates, and has used them in batteries for telegraphic purposes; it has also been platinized, which increases its power. Owing to the greater resistance of carbon and its power of condensing hydrogen, this combination gives a lower current than a silver plate of the same size, and has various inconveniences which render it less economical in the end than silver.

180. The usual form of any of these single liquid cells is that described for the Smee, § 176, but except for the cost of the larger negative it is more advantageous to make this a cylinder as large as the jar will contain. For ordinary or occasional purposes the best mode of construction is to use a jar or a wide-mouthed bottle, and place the negative element in it as a fixed cylinder with wires coming from it to support it, which should be well covered with guttapercha or cement, § 188, and to these a binding-screw should be fixed. The top can be closed with a piece of baked and paraffined wood with a hole in the middle which will just permit the zinc plate or rod to be passed in when required; at other times this opening can be stopped to prevent evaporation.

181. A similar arrangement can also be made with a porous jar secured in the top, and this may contain a saline solution to diminish action on the zinc. In this case, there must be pro-

vided an opening in the top, outside the porous jar, for the purpose of changing the liquid and allowing gas to escape. If the part of the porous jar above the liquid be well stopped with paraffin, § 185 (or if merely a glass tube passes down to below the surface of the liquid), the cell becomes an admirable voltameter, if a small tube is fixed in the top to which a caoutchouc tube can be added to carry the gas away to be measured.

182. *Odds-and-ends Cell.*—Smee proposed what he called an "odds-and-ends" cell, composed of a jar in which a quantity of mercury was placed with scraps of zinc, broken plates, or even raw spelter; a plate of platinized silver was then suspended in the jar and the acid solution added. This has been tried by many, but has seldom given satisfaction. It is, however, well suited to operations requiring a continued current, as the chief objection is the great local action, especially when so constructed that platinum can fall on the zinc and mercury. The following modification, however, will be found useful for working up scrap zinc, as it can be inserted in the liquid just while required. Take a vessel, such as an old porous jar, and pierce its walls with holes, or, make one of guttapercha, which is stronger; the lowest inch or so is not perforated, as it is to contain mercury, to the bottom of which is plunged a stout copper wire, amalgamated at its end, but covered everywhere else with guttapercha and cemented to the side of the vessel, reaching to its top, where it is to be soldered to a binding-screw which is the zinc connection. All the rest of the surface is pierced with as many holes as possible, consistently with strength, to allow free circulation of liquid. It is then filled up with pieces of zinc, amalgamated and in as close contact as may be; the whole acts and is used just as if it were an ordinary plate. The mercury is subject to little waste, but now and then the whole should be removed, well shaken up together, and repacked, and at times the mercury as it becomes charged with metals should be filtered by squeezing through a wet chamois leather, the residue being preserved and added to the collection described § 162. This zinc cell may be used either in any form of single acid cell, or in a Daniell or other cell, within a porous jar.

The cost of such a cell working with zinc worth at most 3*d.* per lb. would be about ·0284 of a penny per unit. For operations on a large scale, perhaps the best form is a cell like Fig. 45, § 188. one side charged with zinc sulphate, having a layer of mercury at the bottom for the scrap zinc, the other containing the silver plate and acid.

183. All the combinations described so far have two faults.

(1) *Weakness.* Owing to the force being largely absorbed by the escaping hydrogen, their electromotive force is low, and any large resistance greatly reduces the current they can yield: their utmost E M F is volt 1·1 and in actual working this will fall to 0·5. (2) *Want of constancy*, as shown by the rapid fall in the experiments, Table IV., which however may be partially overcome by largely increasing the negative surface.

184. Two Liquid Cells.—For many purposes constancy is essential, and it is desirable in all, hence continual efforts have been made to overcome these two defects, and with considerable success, though a really constant battery has yet to be discovered notwithstanding the praises bestowed by manufacturers and patentees on several forms. As yet approximate constancy is only to be obtained by the use of two agents, one acting on the zinc, the other absorbing the hydrogen at the negative plate, and the success is the greater in proportion to the degree in which this negative plate and liquid can be kept in their normal condition as to conductivity and chemical action. Hence they all require a separating medium, as to which a few practical observations will be of value.

185. Porous Jars.—At first, animal membranes, bladders, ox gullets, &c., were employed. In some cases good paper is useful, especially the parchmentized paper. In experiments requiring great resistance, glass tubes plugged with plaster of Paris, or even clay, are employed; for small experiments or for platinizing silver the bowl of a tobacco pipe may be used. For practical purposes, however, unglazed earthenware is universally employed and may be obtained in any form or size. There are many qualities, and they must be adapted to the special purpose. These porous jars act only by the liquid they absorb, and as they very greatly reduce the area of liquid through which the action takes place, of course they greatly increase the internal resistance, and diminish the action; nor is it possible to prevent some mixture of the two solutions thus separated, which causes waste by local action, besides affecting the regularity of the actions. Hence for long sustained action a thick and close-grained jar must be used, while an open and more porous one suits best for short periods and strong action. The most porous ones are of a red colour and soft material, the finest and most enduring are close-grained and white; a good material is soft and may be scraped with a knife. The best test is to fill them with water and see how long it is before it forms a dew on the outer surface; if it runs off, the jar is not fit for use. It is a great improvement to render the bottom, and still more the part which is to remain above the liquid, non-absorbent. If this is not done the salts

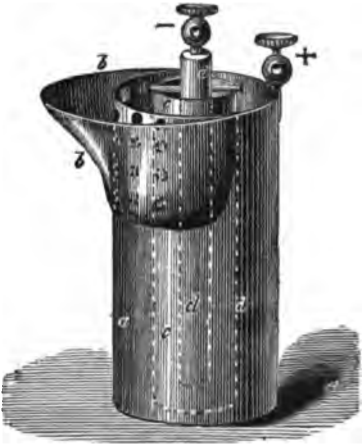
rise up, effloresce, crystallize, and disintegrate the jar. For the same reason jars taken out of the liquids must not be permitted to dry, but should be kept soaking in water to prevent their destruction. This is of particular importance with jars used for the Daniell's cell, as they are very apt to get nodules of copper deposited on them wherever the zinc has touched the inner surface, and particularly at the bottom, where drops of mercury or flakes of zinc fall, and then the cell is very soon rendered worthless; if this occurs, the spot of metal should have some cement or guttapercha laid over it, so as to render it non-conducting. Some porous jars are glazed at the upper part; when this is not the case they should be rendered non-absorbent by standing in a thin layer of paraffin kept just above its melting point, till this has been soaked up as far as is required.

186. ELECTRIC ENDOSMOSE.—Whenever two liquids of different nature are separated by a porous diaphragm they each pass over into the other and become mixed: this action is called *endosmose* and the sole use of the diaphragm is to diminish the rate of mixture. This action occurs in both directions, but when an electric current passes through liquids thus separated, the liquid travels with the positive current, with such a force as to counterbalance a large difference of level. I have known zinc cells to be nearly emptied by this means when a strong current was passing. It appears as though the actual substance undergoing decomposition were not the pure bodies spoken of § 158, but compounds of these with water, and that this accompanies the + ion: but it is also found that the bulk carried by a current is greater with bad conducting solutions than with good conductors. The laws ascertained by Weidemann are: (1) The quantity which flows out in equal times is directly proportional to the strength of the current. (2) The quantities flowing out are, all other conditions being equal, independent of the size of the porous substance. (3) The height to which a current will cause a liquid to rise is directly proportional to the extent of the porous surface. (4) The force with which an electric tension urges a liquid across the partition is equivalent to a pressure proportional to that tension.

187. THE DANIELL'S CELL.—This, the first devised improvement, is also the most successful attempt to obtain constancy. To it also we owe the discovery of the electrotype process, and all it has grown into. Its principle is, that copper, as the negative metal, is surrounded by a solution of a salt of copper, which is reduced; instead of hydrogen, copper is set free, and it is deposited on the negative surface, which is thus kept constantly renewed. The acid of the salt is transferred by electro-

lysis to the positive metal, through the porous medium, hence if a fresh supply of the salt is added to the solution to replace that removed, this part of the arrangement remains constantly in the same condition: but still absolute constancy cannot be obtained, because as the zinc dissolves, the solution belonging to it becomes less active and less conducting. The great drawback to this cell is that the copper salt passes by *endosmose* into the zinc solution, and acts on the zinc where the copper is deposited, and causes great waste by setting up local actions. It is to diminish this that a great variety of forms have been suggested, known by the names of the proposers and patentees, some of which are described below. A plan I have found to answer with large cells for long-continued experiments in which constancy was important, is to use a larger porous jar outside the zinc one, filling the space between them with a strong solution of zinc sulphate, and some zinc cuttings to decompose any copper salt entering; the inner cell is thus kept nearly free, but of course the internal resistance is somewhat increased. The ordinary form of the Daniell is shown in Fig. 44: *a* the copper vessel fitted with a reservoir *b* for the crystals, *c* the porous cell, *d* the zinc rod suspended in it by a bar passing through it. The part of the copper cylinder within the reservoir is of course perforated, and should be well varnished. Modes of construction may be varied to any extent. Thus instead of a copper containing vessel, a glass or earthen jar may be used with a cylinder of sheet copper, or such a jar may be covered inside with a film of wax, blackleaded, and the deposited copper will form its own surface, but the first is the best plan, especially as the sulphate of copper has a great tendency to climb up glass surfaces, on which it crystallizes and finds its way by degrees to the outside.

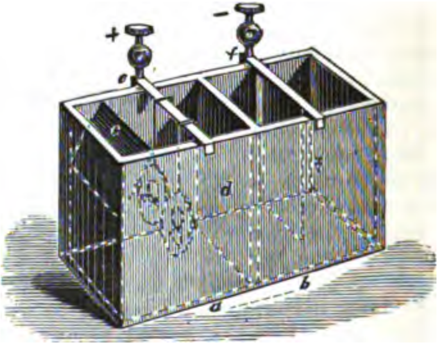
FIG. 44.



188. Instead of cylinders, flat plates may be used in a vessel across which a plate of porous material is fixed, and this form has several advantages, among others it is easy to make the cell

itself serve as a depositing vessel by using models, seals, &c., in fact any object we wish to copy, as the negative surface, by suspending these to a rod which forms the + pole of the battery. This is in fact what is called the single-cell process of electrotyping. In this case the cell is best made of wood, lined with a resinous cement; guttapercha may be used, but has the disadvantage of facilitating the *creeping* process of acids and salts, which is troublesome and messy, besides causing loss of power by establishing paths by which the force escapes. Four parts resin melted with one of guttapercha, and a small quantity of boiled oil answers perfectly; the wood should be perfectly dry and warm when it is applied. A similar cement with a larger proportion of guttapercha may be used for covering wires, first heating them so as to insure adherence; for this purpose it should be run into sticks. Such an apparatus is shown in Fig. 45: *a b* is the box divided by the porous partition *d*; *c* is a place for holding the crystals; *e* and *f* are two bars of metal, to which are hung the objects to be copied and the zinc plate, and each is fitted with the necessary binding-screw. The bars being movable, it is easy to regulate the distances, and so to control the action, by altering the internal resistance. This apparatus answers admirably for a voltameter by using a light copper plate and weighing it after the conclusion of an experiment, § 350.

FIG. 45.



The Daniell cell will also serve as an approximate measurer of current by the solution of the crystals. As these contain one-fourth their weight of copper, the quantity needed for a given work is easily calculated, and if this is put in the reservoir, when dissolved it will indicate the completion of the work: or if it is desired to deposit a particular weight of copper, the completion is shown by the fact of solution if four times that weight of crystals is placed in the receiver: but sulphate of copper is often very impure, iron and zinc replacing the copper, and therefore the salt should be examined.

189. Instead of a fixed porous partition a flat porous cell may be used to contain the zincs, so as to have copper on both sides. In this and in other cases a convenient connection to the zincs is a bar of wood crossing the cell with a deep channel in it to contain mercury or a row of mercury cups let in it, all connected by stout copper wires to a binding-screw at the end of the bar; the zincs have a stout copper wire soldered to or cast in the upper end, and this is bent over so as to dip in the mercury, and allow the zinc to be instantly removed and exchanged: or a row of common porous cells may be used, so that the zincs may be removed for cleaning, &c., one at a time, without much affecting the current; such cells may also be distributed about among a number of plates or objects, in order to secure equal distribution of the action.

190. The fluid surrounding the zinc may be the usual acid, or where rapid action is not needed, as for telegraph purposes, pure water; the best solution to use when constancy is desired is a half saturated one of sulphate of zinc, which is kept in proper condition by occasionally removing a little and replacing with water. Sal-ammoniac or common salt have been used, but are objectionable as they find their way to the copper and produce an insoluble deposit there when the battery is out of action. With neutral solutions the zinc need not be amalgamated: the zinc should be removed occasionally and the deposited copper brushed off, and when a battery is required only at intervals, the zinc solution should be emptied into a jar with a few scraps of zinc to reduce any copper. As during action the current tends to drive the solution towards the copper, and thus resists the endosmose of the copper towards the zinc, § 186, it is desirable, when a battery is out of action, to close its circuit through a moderate resistance, so as to maintain a small current. In fact it is found with the Daniells used in telegraphy, consisting of porous cells greased everywhere except upon a surface sufficient to allow the required action, that the expense of maintenance is about the same whether they are working or not, owing to this action of endosmose.

191. The theory of the action of the sulphate of copper cell

is easily explained as an extension of that shown Fig. 42, § 101. If we consider the two molecules to the right of the porous partition to be sulphate of copper,

We have,	Zinc	$\overbrace{H_2SO_4}, \overbrace{H_2SO_4}$	$\overbrace{CuSO_4}, \overbrace{CuSO_4},$	Copper.
polarized		$\overbrace{SO_4H_2}, \overbrace{SO_4H_2}$	$\overbrace{SO_4Cu}, \overbrace{SO_4Cu}$	
breaking up		$\overbrace{ZnSO_4}, \overbrace{H_2SO_4},$	$\overbrace{H_2SO_4}, \overbrace{CuSO_4}, Cu$	

The last line shows that what occurs is that an atom of zinc is taken up and one of copper displaced, that the source of the force is simply the difference between the affinity of sulphuric radical for zinc and for copper; the acid serves only as a conductor, as it will be seen that there is the same quantity after action as before; the force yielded is equivalent to the heat zinc would give while precipitating copper from its sulphate, and is really the difference between the internal force necessary to the existence of sulphate of copper, and that bound or latent in sulphate of zinc.

192. *The Electromotive force of the Daniell.*—It is usually stated to be volt 1·079, but is subject to many causes of variation which have been only slightly studied, which is, no doubt, the reason that good authorities differ as much as 3 per cent. in the value. Dr. Alder Wright calculates the value from the chemical reactions as 1·105, and says that the specific gravity of the liquids, i. e. the strength of the acid, plays so important a part that with acid specific gravity 1·010 (see table p. 126) the EMF is 1·123; at 1·050 it is 1·133; and at 1·090 it is 1·143. Other authorities say that with sulphate of zinc it is 95 per cent. of that with acid. My own experiments indicate that there is not much difference due to this cause. I found that in such delicate experiments where no real working current is developed, what is measured is really static potential rather than EMF; the mere motion of the zinc plate, or brushing off the bubbles of hydrogen would make an instant change of 3 per cent., and that therefore this action alone if unknown (and I have never seen it noticed) would vitiate many observations.

193. Dr. Wright states "it was found that but little difference was produced by using pure, commercial, or amalgamated zinc, or zinc coated with a film of copper." This is entirely different from the received opinions, and very different from my own experience. I find that amalgamated zinc has the higher force by about ·01, as compared with new sheet-zinc, and more as

against corroded zinc, and that the E M F of any zinc plate is always increased by cleaning off the residuary impurities, and renewing the amalgamation.

The effect of copper deposit on the zinc is very marked, and may be easily tested; if the zinc plate be touched with a copper wire the force falls ·03. This is not, as sometimes said, an effect of *contact* lowering the potential; it is a direct chemical action: there was already a copper contact in the wire conductor soldered to the zinc; in fact, merely touching with copper out of the liquid produces no effect; the copper must be under the liquid, so that it sets up a local action. I found that by adding a little copper sulphate to the zinc solution, so as to throw down copper on the zinc plate, the force fell ·03, and then the touching with a copper wire produced no effect. It is evident, therefore, that where a constant E M F is desired, the zinc plate used should not be free from copper. But all loose deposits of copper should be removed at intervals.

194. *Variation of temperature affects the E M F.*—Heat raises the force; it does so by affecting the solubilities of the two salts, and supplying externally the energy absorbed in solution. I find that between 32° Fahr. and 52° there is a difference of volt ·01, and between 50° and 60° also ·01, and between 50° and 100° about ·025.

195. These experiments were carried out by means of cells consisting of U-tubes; the bends of which contained sand mixed with oxide of zinc, to prevent passage of the copper salt. I found these remained in perfect action for a week without a trace of copper passing; the tubes were mounted in stands with mercury cups, and the plates of metal had wires attached, so that they dropped into the cups as the plates were inserted in the tubes, and could be readily exchanged. Of course the object in such experiments is to isolate each action and obtain theoretical perfection at the moment, in order to ascertain whence come the defects which arise in more practical operations.

196. It is generally considered that the Daniell is not subject to "polarization"; that is to say, that its E M F is constant whatever the external resistance may be: this is not exactly the case: it is affected by the "density of current" derived from it. According to Dr. Wright a surface of 125 sq. centimetres (19·5 sq. inch) will maintain its E M F up to a current of ampere ·001, and will lose 1 per cent. if called on to produce ·006, and as much as 10 per cent. if worked to ampere 0·4. These figures are, however, entirely special, applying to a particular construction. The cause at work is very clear; it is,

that the current developed must be proportioned to the supply of copper salt presented to the copper plate: if the solution is not strong enough to meet the demand, we have copper, not in copper salt, but in sulphuric acid, because the copper has been removed from the molecules adjoining the plate: this can only be corrected by the process of diffusion. His battery appears to have been arranged for the particular purposes of his experiment, in the manner least adapted to actual working, with the copper plate at the top in a weak copper solution floating above a denser zinc solution. The best arrangement for constant E M F would be the exact reverse, so as to send the dense copper solution streaming to the copper plate. Various forms devised to attain this object, and do away with the difficulty and waste of endosmose will be found in the following sections.

197. *The Daniell cell* has been fully examined because of its importance, both practical and theoretical, and it only remains now to show the cost of its working. In this instance, this is shown in full detail, and will serve to show how the cost of the other forms has been arrived at in Table VI. § 252.

The local action will depend on the quality of the porous vessel, rate of working, &c., but we may allow 5 per cent. We have then per unit, by Table V. § 251:—

Line 24	Zinc unamalgamated	·0195
„ 9	Copper sulphate	·0900
	Local action	·0055
		·1150
Less 8	Copper reduced	·0566
	of a penny	·0584

This assumes that zinc sulphate is used in the zinc cell and costs nothing, it being a product of the working. The reduced copper is taken at the common value, but if it is deposited in useful forms the actual cost of the cell will be reduced to nothing in many cases.

In fact it is so worked in some factories, where large cells are so arranged that the copper plates are objects receiving deposit, such as stereotype blocks, while current is led from them to other work.

198. THE GRAVITY BATTERY is a Daniell without a porous cell, in which the copper solution is kept from the zinc only by its

greater specific gravity, but gradually reaches it. There are many forms, but it was first proposed by Mr. Varley.

In *Callaud's* form, much used in American telegraphy, the bottom of the jar is covered with a sheet of copper fitted with a wire conductor, upon this is laid a stratum of crystals of copper sulphate, which should be large if a small current is wanted, small when much work is to be done; the zinc plate is suspended above and the jar charged with water, or a weak solution of sulphate of zinc; it must of course be placed where subject to no vibrations or disturbance.

Lockwood's spiral claimed to maintain the separation of the different liquids by means of a kind of repulsion set up by the electric current. The negative element consists of a stout wire wound in a flat helix, which occupies a position about the middle of the vessel, the wire then descends from the middle of this, either in a straight line or a spiral, and forms another helix spreading over the bottom of the vessel, from which it rises in a guttapercha tube to the top of the vessel, terminating with a binding-screw: all the turns of the wire are to be in the same direction, so that all the parts of the current are parallel. Experience does not show much gain in this construction.

199. *Central reservoir of crystals.*—In the various forms of gravity cell, instead of a stratum of copper sulphate in the bottom, a tube or funnel may occupy the middle of the vessel and contain a supply of crystals, while the zinc is either a vertical cylinder, or a ring cast conical, so as to surround the central tube: the conical form allows escape of the hydrogen which forms, and assists the falling off of precipitated copper. In some cases the bottom of the tube is closed with a cork containing a glass tube of such size as to limit the outflow of the saturated copper solution: in this case it is preferable to add another bent tube rising about one-third the height so as to supply fresh solution from the exterior and maintain the flow.

The most satisfactory arrangement I have been able to devise after many trials is one of this character in which the opening of the outflow tube is fitted with a plate of soft indiarubber which can be pressed up to and close it when the battery is not wanted for action: it is desirable also to close its circuit through a considerable resistance at such times so as gradually to use up the copper solution.

The *Meidenger cell* is on the same principle; the reservoir of crystals is a flask, the neck of which replaces the tube just described and is similarly fitted; being closed from atmospheric pressure, the supply of solution is very gradual, being governed by the principle of the bird fountain. All of these work best for a small gradual demand, but do not answer well if left out of action for some time and then called on to supply large current.

200. The *Minotto* has been much lauded; it consists of a jar, at the bottom of which is a copper plate, fitted with a wire, this is covered with an inch of crushed sulphate of copper, and this again with a layer of silver sand which is to act as the porous division. Some use sawdust instead of sand, others paper pulp, or felt; they are useful for some purposes in which a great internal resistance is not an objection, but the copper inevitably finds its way to the zinc. Animal charcoal offers the greatest protection against this, owing to its property of absorbing metallic salts; but this very property causes it also to form a nearly solid mass, in a little while, and then its resistance becomes enormous.

201. M. Gaiffe has devised a form of Daniell for occasional uses: it consists of a compound inner cell, the upper part of which is alone porous; this contains the copper and copper salt. The outer cell contains zinc in form of a ring at the top of the cell, and a plate or wire of copper at the bottom connected to the ordinary copper pole: the idea is that as the copper salt passes through the porous cell it will sink by its greater specific gravity and form a stratum at the bottom. When circuit is closed, the resistance between the zinc and the external copper being less than that to the interior of the cell, this outer stratum of copper salt will be first reduced.

I have modified this by making the inner cell consist of a copper cylinder fitted with an upper part of porous earthenware cemented to it, and have also placed the zinc in the inner cylinder. This cell is useful for many purposes, but cannot be relied upon as a steady electromotive force, and copper salt does reach the zinc, though not nearly as much so as in the common form.

202. The next great class of generators includes those which employ at the negative plate some substance containing oxygen in a state to be readily given up. The ingenuity of inventors has been much exercised in devising variations of (1) the negative plate, (2) the oxidizing agent, this latter being either liquid or solid. The principles and qualities of the many different forms will be much better understood by keeping this classification in view, than by a mere description of particular forms.

Any substance which will react freely on nascent hydrogen can, of course, be employed, and those liquids which contain oxygen or chlorine in a condition to be freely given up answer best; of these nitric acid is the most powerful, while bichromate of potash gives no fumes, so that these substances have proved the most valuable in practical use.

203. *Nitric Acid.*—This is a solution of the true acid HNO_3 and varies greatly in strength. The following table shows the value of the most important strengths:—

TABLE III.—STRENGTH OF NITRIC ACID.

	Specific Gravity.	Percentage HNO_3.	Equivalents or atoms per lb.	Atoms in 1000 liquid grains.
1	1·5210	100·	111·11	21·4
2	1·4518	77·777	86·42	17·90
3	1·4200	70·000	77·78	15·78
4	1·4000	66·	73·	14·49
5	1·3945	64·156	71·28	14·19
6	1·3732	60·437	67·15	13·17
7	1·2462	39·063	43·46	7·70
8	1·2402	38·121	42·36	7·51

1, is the theoretical acid, formerly called the 1st hydrate.

2, is $2\,HNO_3 + 2\,H_2O$, formerly called the 2nd hydrate.

3, is $2\,HNO_3 + 3\,H_2O$. This distils unchanged at 248° Fahr., and is the strength to which boiling brings both stronger and weaker acids.

4, is an ordinary commercial strength.

6, is double aquafortis.

8, is single aquafortis.

An impure fuming acid is obtainable which cannot be valued by sp. gr., as it contains sulphuric acid and other substances, but serves very well for battery use. The best test for acid for this purpose is a small Grove's cell, into which a measured quantity can be placed, so that the current it generates on a known galvanometer, and the time it will maintain it, can be observed.

204. *The reaction* which occurs is very complicated, and varies at different stages of the action. HNO_3 may lose one atom of oxygen, becoming HNO_2 nitrous acid, under two units of action which provide H_2 to form H_2O water: but one atom of hydrogen is equally able to take up one of oxygen together with the hydrogen of the acid; thus $HNO_3 + H$ becomes $H_2O + NO_2$; or, the same reaction taking place with the residue (nitrous acid) of the first case, $HNO_2 + H$ becomes $H_2 + NO$. Part of the acid is even totally deoxidized and converted into ammonia, which unites with the acid, and may then be reduced to nitrite.

In each of these cases the work done electrically by one atom of acid would be different; and for this reason the electromotive force falls off as the action proceeds. When cells are used for producing large currents, the reaction which occurs is confined to the giving up of one equivalent of oxygen to one of hydrogen; this reaction, which must be considered the normal one to which the E M F of 1·8 volt corresponds, continues as long as the strength of the acid is over sp. gr. 1·26, but from that point the E M F lowers and on the other hand more economical reactions take place. It is evident, then, that the action ought to be considered from these distinct points of view.

205. When the battery is working for great force and current, the acid should not be reduced below sp. gr. 1·246, line 7 of the table, and, therefore, the working power of the acid is really 73 − 43 = 30 units, leaving nearly two-thirds as much behind unused, besides whatever oxygen might be utilized beyond the first equivalent.

This acid is, therefore, available for further use, for purposes in which so great E M F and such steady constancy are not necessary: it might then be reduced to sp. gr. 1·16, at which strength it would still retain about 23 per cent. of acid; but the reactions would have given 3 equivalents of oxygen in place of 1, and, therefore, the work of the pound of acid would be 73 − 23 = 50 × 3 = 150 units.

Besides the consumption of material needed for the current, there is a waste by endosmotic actions of from 6 to 10 per cent.

206. It is usual to employ sulphuric acid to act on the zinc; but it is well known that hydrochloric acid gives at least 5 per cent. higher electromotive force—that is, the E M F would be over 2 volts with HCl as against 1·8 with H_2SO_4; besides which the chloride of zinc formed is very soluble, and will not creep up the cells and crystallize as the sulphate does. Sulphuric acid is preferred from habit and because it is cheaper, though this is only a small part of the cost. Hydrochloric acid may be objectionable also, as giving off fumes, but while this is a legitimate objection in most batteries, it is of no moment in presence of the more objectionable nitrous fumes.

Saline solutions are sometimes used in the zinc cell, but this is bad economy, as it results in the solution of the zinc being really effected by the nitric acid, of which therefore double quantity is used. But such solutions, and preferably a half-saturated solution of zinc sulphate, may be used if the equivalent proportion of sulphuric acid be added to the nitric acid in the porous cell.

Chloride of zinc may be used in the zinc cell, or, as the acids will pass through the porous cell, it is only necessary to occasionally replace part of its contents with water when the conditions allow this.

207. Aqua regia.—But the employment of hydrochloric acid brings about another result—viz. the use of a mixture of nitric and hydrochloric acid in such a manner as to utilize chlorine as the active agent in place of oxygen, and thus regenerate the acid.

I believe the actual use of *aqua regia* and hydrochloric acid is due to M. d'Arsonval, as the result of a series of valuable experiments on the working of batteries; but, of course, it has long been known that chlorine and the various similar substances which will unite with nascent hydrogen are available in the battery. M. d'Arsonval recommends an *aqua regia* composed of equal volumes of nitric acid sp. gr. 1·33, and hydrochloric acid with a volume of water equal to the acids. The object of the dilution is to prevent the forming of nitrous fumes, but it is obvious that the EMF must be lower. There is also an advantage in using water containing 1 in 20 of its bulk of H_2SO_4 instead of simple water.

208. *Chromic acid.*—Batteries in which bichromate of potash is used act really by the chromic acid which is set free by the action of another acid, usually sulphuric.

Bichromate of potash is not a true twofold acid salt like bisulphate of potash, but consists of one atom of chromate of potash and one of chromic anhydride, K_2CrO_4,CrO_3. Its formula is generally written as K_2O2CrO_3, or $K_2Cr_2O_7$, making its atomic weight on the new notation 295·2.

It is commonly supposed that the effect of the addition of sulphuric acid is to convert the potassium salt into chromic acid and sulphate of potash. But be the preliminary action what it may, the effect of the action of the battery is to convert the salt into chrome alum. The usual modern formulæ rather disguise this action, which is, however, quite intelligible when we regard an alum in the old fashion as a combination of a sesqui-sulphate $M_2^{IV}\,3SO_4$ with a proto-sulphate M'_2SO_4 crystallizing with 24 atoms of water. The tetratomic metal, uniting two atoms, so as to have a valency of 6, being either alumina, iron, chromium, &c., while the monatomic base is usually an alkali, potassium or ammonium.

209. The action can be stated as

$$\left.\begin{array}{ccccccccc}
\left\{\begin{array}{l} K_2CrO_4 \\ \quad CrO_3 \end{array}\right\} & + & 4H_2SO_4 & = & \left\{\begin{array}{l} K_2SO_4 \\ Cr_2 3SO_4 \end{array}\right\} & + & 4H_2O & + & 3O \\
295\cdot & & 392\cdot & & 567 & & 72 & & 48 \\
3Zn & + & 3H_2SO_4 & = & 3ZnSO_4 & & & + & 6H \\
195 & & 294 & & 483 & & & & 6
\end{array}\right\} 3H_2O$$

That is to say, 1 atom of bichromate of potash with 4 of sulphuric acid gives oxygen equivalent to the hydrogen derived from 3 atoms of zinc acting on 3 of sulphuric acid. This is equal to 6 units of current, and makes the electric equivalent of the potash salt under these conditions, about 50 grains, which quantity requires 66 by weight, or 38 by measure, of sulphuric acid to effect its own decomposition. If the acid to act on the zinc is to be provided in the same solution, an additional equivalent is needed, making the quantity for each unit of work 115 grains by weight, or 66 by measure.

210. Owing to the insolubility of the salt, the solution is weak, a pint being only about 25 units, therefore a large porous cell must be used, unless the zinc is placed within. The usual directions for preparing the solution are to dissolve 3 oz. of the salt in a pint of water by aid of heat; and when cool add one-twelfth its bulk, or 2 oz. of sulphuric acid; but this is erroneous; it only supplies the first 4 equivalents of acid, and though given for single-cell bichromates, is only suitable for a double-cell in which acid is used besides to dissolve the zinc. In order to utilize the salt completely, a nearly equal quantity of acid should be added, when the action becomes sluggish; if added at first it causes too great local action, and this is always very great.

The electromotive force falls rapidly, and the resistance increases with this solution, as the chromic alum forms; this also frequently crystallizes in the solution and upon the carbon.

211. *Hydrochloric acid* used instead of sulphuric avoids many of these defects. The solution can be prepared with equal volumes of the cold saturated solution of bichromate of potash and of hydrochloric acid. The combinations of chromium are so complicated and so easily modified by conditions of temperature and saturation, that it is difficult to say what actually occurs: but the following expressions appear most probable:—

$$\left.\begin{array}{l} K_2CrO_4 \\ CrO_3 \end{array}\right\} + \begin{array}{l} 2HCl \\ 2HCl \end{array} = \begin{array}{l} 2KCl + H_2CrO_4 \\ H_2CrO_3Cl_2 \end{array}$$

That is to say, 1 molecule (or atom) of bichromate of potash, 295, with 4 atoms of hydrochloric acid, is resolved into 2 of potassium chloride (which then passes out of consideration), 1 of chromic acid, and 1 of a chloro-chromic acid, in which Cl_2 replaces 1 atom of oxygen. These two acids now react upon the hydrogen derived from the action of zinc upon the acid thus:—

$$\begin{array}{ll} H_2CrO_4 + 2HCl & = CrCl_2 + H_2O + O_2 \\ H_2CrO_3Cl_2 & = CrCl_2 + H_2O + O_2 \end{array}$$

The complete reaction may be expressed also as

$$
\begin{array}{rl}
295\left\{\begin{array}{l} K_2 \\ \left.\begin{array}{l} CrO_4 \\ CrO_3 \end{array}\right\} \end{array}\right. \begin{array}{c} + \\ + \\ + \end{array} \left\{\begin{array}{l} 2HCl \\ 2HCl \\ 2HCl \end{array}\right. & \begin{array}{l} = 2KCl \\ \\ = 3H_2O + 2CrCl_2 \end{array} \\
260\ \ 4Zn \quad + \quad 8HCl & = 4H_2O + 4ZnCl_2 \\
\overline{} & \\
511\ \ HCl \qquad\quad 14 &
\end{array}
$$

Hence, 1 molecule (295) of the salt with 6 atoms HCl is equal to the production of 8 units of current, requiring a further 8 atoms (14 in all) of acid to dissolve the 4 atoms or 8 equivalents of zinc. In this case, therefore, the equivalent of the salt is only 37·5, because it is wholly reduced to neutral chloride instead of to sesqui-sulphate, as in the other case; each unit, therefore, requires 1 unit of acid for its own reaction, and 1 unit either in the same or a separate cell for the zinc. No crystals form in this solution.

212. *Chromate of calcium* would be very useful if it could be obtained in the market, especially as its residues are easily converted into valuable colours, which is not the case with the potash salt because the alkali cannot be completely got rid of. The use of this salt was proposed by Mr. D. G. Fitzgerald and the description of it in the first edition has led to so many inquiries that it is necessary to explain that, although actually produced in the process of making the potash salt, it is not prepared for the market, owing to there being no large demand; it ought to be considerably cheaper than bichromate of potash. It can be prepared by those who wish it for use by dissolving 5 parts of bichromate of potash in boiling water, and adding 1 part quicklime (just slaked before use), and 2½ parts of plaster of Paris. It will come down as a yellow powder, which contains an atom of water and has an equivalent of about 60 grains per unit, and requires one-fifth more acid than the potash salt. One-half the lime is thrown down as sulphate on the addition of the acid, and the rest precipitates during the action.

It takes one atom more acid than the potash salt, the reaction being

$$
\left.\begin{array}{l}
\left.\begin{array}{l} CaCrO_4 \\ CaCrO_4 \end{array}\right\} + 5H_2SO_4 = \left\{\begin{array}{l} 2CaSO_4 \\ Cr_23SO_4 \end{array}\right. + 3O \\
3Zn \qquad\quad + 3H_2SO_4 = \quad 3ZnSO_4 + 6H
\end{array}\right\} 3H_2O
$$

213. Another solution which might be useful is prepared by adding to 3 parts of bichromate in solution, 1 part by weight of oil of vitriol, and 6½ parts of sulphate of alumina (Al_23SO_4

$+ 18H_2O$), or so much of any quality as will, after concentration and cooling, remove the potash as alum. The solution will require sulphuric or hydrochloric acid sufficient to satisfy the reactions.

214. *Voisin's red salt* is very convenient for amateurs who do not wish to have the trouble of acids; it is a compound salt containing the necessary acid in the proportion of the formula § 209. It gives the same E M F as the ordinary solution, and appears to be rather more constant, but produces a somewhat greater resistance. It should be dissolved 20 to 25 parts to the 100 of water. That is, 4 oz. to 5 oz. in a pint. It consists of

$$\underset{140}{Na_2SO_4} + \underset{686}{7H_2SO_4} + \underset{295}{K_2Cr_2O_7}$$

which is probably changed by the action into

$$2NaHSO_4 + 2KHSO_4 + 2CrO_3 2SO_3 + 7 \text{ water.}$$

It is made by dissolving the sulphate of soda in the heated acid and gradually stirring in the bichromate; it is then poured into moulds, and after cooling, removed and broken up.

215. *Nitric acid with bichromate of potash* has been highly spoken of by some writers as giving a constant current and no fumes. It is true that the constancy of the current is improved, but after a little time the fumes are given off; the reaction is simply the reoxidation by the bichromate of the reduced nitric acid. Still this plan may be useful where a strong current is required for a given time, as for producing the electric light. The solution recommended is a saturated solution of bichromate in nitric acid, with one-third volume of sulphuric acid added and just enough water to redissolve any chromic acid precipitated.

216. *Alkaline nitrates* have been proposed in place of nitric acid; nitrate of ammonia, even, has been employed, but it is expensive and has no sort of compensating advantage. When a solution of these nitrates is mixed with sulphuric acid, a reaction takes place by which the base is divided between the two acids in ratios depending on the relative proportions present; hence results a solution containing a proportion of free nitric acid which acts in the usual manner, while the remaining nitric acid is only set free as the action of the battery proceeds. Nitrate of soda is the best; it is cheaper by the pound, its equivalent is lower, and therefore the pound does more work, and it is very much more soluble, and therefore a much more active solution is obtained. It is not, however,

generally known that water, when fully saturated with one of these salts, will still dissolve nearly as much of the other as though it were pure water, and thus the strongest solution is made by dissolving both the salts together. With nitrate of soda at *2d.* per lb., the cost of the atom of nitric acid obtained from it in the cell is ·0456, against ·1096 of the acid. But such solutions have a vastly greater resistance than the simple acids and are not fit for generating energetic currents.

217. *Any substance containing oxygen in unstable combination* may in fact be used at the negative plate, and inventors and patentees are fond of giving their name to and claiming the use of these. Thus solutions of chlorate or permanganate of potash, chloride of lime, and many other substances are available, and may be useful under some circumstances, as to which see also §§ 245–6.

218. BATTERY CONSTRUCTION.—The forms of cell are variable, and instead of describing particular forms such as square and round, it appears better to explain the principles involved, which can then be adapted to suit circumstances: thus we have two names for nitric acid batteries; but the *Grove* is simply a cell in which platinum is used as the negative electrode, and the *Bunsen* is one in which carbon is substituted. We are practically limited to these two substances; all others which have been proposed may be dismissed in a few words.

Iron, whether wrought or cast, though often praised, and used long ago in the Callan and Maynooth batteries, is a mere means of waste and annoyance: it assumes what has been called the *passive state*, in which strong nitric acid has no action on it. This state consists in the formation of a film of iron oxide, insoluble in the strong acid. When the acid weakens the protection fails, the iron is suddenly acted on, and the acid boils over.

Aluminium has been suggested, as not acted on by nitric acid, a somewhat doubtful statement: at all events, its EMF is lower than that of carbon, and this means waste of the acid and zinc.

219. PLATINUM.—This is by far the best, except for its first cost, against which must be set the fact that after prolonged use it has two-thirds its first value, and is not diminished in quantity. As a rule platinum is used too thin, which has the double defect of liability to injury and of producing resistance, as the metal is low in conductivity.

Byrne's negative plate, which excited much interest a few years ago, was composed of platinum backed with copper incased in lead, which seems unnecessary complication, as a thick sheet of lead would answer perfectly: but the system offers a promising suggestion as to the use of a plate of lead or copper completely inclosed in thin platinum by means of a solder not acted on by the acid. If deposited metal were not porous an excellent plate might be produced from it in this manner.

Surface of plate is of great importance, and it is well to corrugate the platinum vertically, both to increase the surface and to give rigidity to the metal; it is also an improvement to deposit very slowly a coating of crystalline platinum.

220. CARBON.—This is, electrically, as good as platinum; in fact it appears to have a slightly higher E M F. The objections to it are its brittleness, its tendency to soak up the liquid, the difficulty of making a good connection to it, and the combination of these in eating away the metal contacts and forming some non-conducting substance at the junction. Carbon has several allotropic forms, as the diamond, charcoal, and graphite or plumbago. It is the last which is useful for batteries in its form of gas-carbon. This is *not coke;* coke is the solid residue left after distilling coal; the graphite comes from the *gas*, the rich hydrocarbons of which are decomposed by contact with the heated retort, on which they form a shell; it is, in fact, a great nuisance to the gas-maker, as it arises from the destruction of the richest gas, injures the retorts and wastes the heat; in the gas-works it is called "scurfing." The densest and hardest is the best for electrical use; it should be almost non-absorbent, and ring like a metal when struck, and have a clear grey colour, not black. The best mode of cutting carbon is that employed by stone-cutters, by means of a piece of iron, sharp silver sand, and water; important elements of the process are time and labour, for the material, if good, is very hard to work, and this is the chief element in the cost.

221. ARTIFICIAL CARBONS.—Plates or blocks may be built up from powdered graphite mixed up with coal-tar or strong rice paste dried, heated, then packed in powdered carbon in a closed vessel and heated to clear red for some time. When cool they should be soaked in strong syrup of sugar or treacle, again dried and treated as before; this process must be repeated until the carbon is perfectly dense and strong. In this way are made cylindrical vessels, left somewhat porous to hold the acid and act the twofold part of porous jar and negative plate; many of the plates and blocks in batteries of French make are thus made, and work fairly well, but under some chemical reagents they break up.

A new quality of carbon made in this manner is now at our disposal in the thin rods (true carbon wires) made up for the electric arc lights, which are also useful for resistances: they are valuable for batteries because of their density and freedom from cracks, as also for the ease with which they can be arranged to give large surface in small space.

Battery plates, &c., are also made of plumbago crucible material, but this soon disintegrates. Faure's battery is made of this material in exactly the form of a ginger-beer bottle: this contains the acid under a pressure caused by the gases given off, which are retained by means of a graphite stopper ground in, which also serves for the connection of the cell, being fitted with a binding-screw.

222. CONNECTING CARBONS.—This is the great difficulty; it is commonly done by fixing a clamp on the end, when a piece of platinum ought to be interposed between the two surfaces. A better plan is to deposit copper on the upper part, and then solder the connection to it, as this gives continuous circuit; the copper takes on it just as it would on a metal. There is one drawback to this, the same in fact which requires the platinum interposed in the first plan; the acid both creeps up the surface and soaks into the substance, and then acts on the copper and destroys the connection. The following plan, which I proposed many years ago, is a protection against this, *provided it be thoroughly carried out*:—

Heat the end of the carbon, and touch the part just beyond where the copper is to extend to (which should be about half an inch from the end) with a piece of paraffin, taking care it does not run up the part to be deposited on; should it do so, it may, however, be driven off by strong heat; when cold, cut a few scores in the surface to give a hold to the copper, and drill a hole through, in which fix firmly a copper wire projecting on each side; now with a warm iron spread a good film of paraffin from the line of the intended coppering as far down the carbon as the part to be immersed in the liquid of the battery when working. Connect a wire to the carbon by a screw clamp, and insert in a copper solution, arranging at first for a quick deposit to prevent entrance of moisture into the pores of the carbon. When a good deposit is made, drill a few holes right through copper and carbon, soak in water to remove any absorbed copper salt, and dry it thoroughly. Now tin the part to which the binding-screw or connecting-wire is to be soldered, and stand the carbon with its coppered part in a vessel containing a little melted paraffin till its upper part is well saturated, the holes being intended to insure this. When the connection is soldered a coating of paraffin may be spread with an iron over the copper, and all parts of the carbon not intended to be acted on by the liquid. No cement is of any use for this purpose, paraffin alone resists powerful oxidants, such as nitric acid, and it is equally a protective against caustic alkalies.

223. SURFACE.—This is of even more importance than with platinum. There are many uses for powerful batteries in which the object is a powerful current for a limited time, an hour or two: for these a cell which would only hold just sufficient nitric acid for the occasion, would be valuable; but to get this we need a porous cell which will only just hold this quantity, and which shall yet have in it a plate surface capable of generating the required current. Again, the chromic acid cells fail very rapidly, owing to polarization, and a large negative surface is the best remedy. There are two modes of attaining these objects.

Granulated carbon may be packed in the cell around one or two plates or rods serving as conductors, in the same manner as in the manganese cells: the connection to the separate particles is, however, imperfect at best, so the resistance is large. The plan is only available with acids, either as a Smee, or with nitric acid: it is not suitable to any chromic salts, as these tend to forming deposits on the surfaces, which break the connection.

Carbon rods, § 221, may be packed into the cell with such space as is desired for the liquid, their tops being all connected together.

224. INCLOSED CELLS.—These are very convenient, and either form of carbon can be used in them. The space within or around a porous cell can be used, and of course the outer space gives most room. I have found it convenient to use a porous cell perforated with holes fixed into the containing vessel, using a second porous cell for the zinc, which is inserted in the other only when required for use. The oxidant can then be left in the containing vessel for further use, and the opening closed with a stopper. I thought I had arrived at perfection and done away with the nuisance of charging and emptying nitric acid cells, but there is an *if* in the way; the plan would be perfect *if* we could find a perfect means of inclosing the top: as it is I can only describe the best results I have attained.

Arrange the carbon conductor in the cell, and also a glass tube for supplying the liquid, reaching nearly to the bottom: then shake in dry sand, if rods are used, or salt, if with granulated carbon, filling to within an inch of the top. On this place a well-fitting layer of cardboard boiled in paraffin, in a hole in which is inserted a piece of glass tube just entering the sand. Now, *after warming the tops of the cells*, which ought to have been stood in paraffin before use so as to be coated, pour in melted paraffin just about to set. I have tried running in plaster of

Paris, and after drying have turned the cell upside down in melted paraffin, allowing it to soak into the plaster and form a stratum the thickness of which can be controlled by the depth to which the vent-pipe enters the cell; but the paraffin breaks up into minute fissures, and ultimately the plaster disintegrates. After all is set, the sand can be shaken out through the vent-pipe, or the salt dissolved.

It is possible that for some uses the sulphide called Spence's metal might answer the purposes of a cement to close such cells.

Another plan, available with rods, is to make a cylinder of sheet metal, slightly smaller than the cell, as a mould: arrange the rods in this as just described, and then run in melted lead. This can then have asbestos yarn wound round it, and after placing in the true cell, be cemented in as in the other case.

225. CIRCULATION OF LIQUIDS.—The chromic acid cells always lose power very quickly, and the reason is that the solution in contact with the negative surface is exhausted: therefore the rate of possible current is limited by the capacity for renewal of this solution by diffusion, which is a slow process. This means, as in other cases, that there is for every kind of action a definite ratio between current and surface. This is why enlarging the surface maintains electromotive force more constant, although *surface per se is no function of EMF.* Consequently, any means of keeping active solution in contact with the negative plate maintains the EMF. In nitric acid this is effected by the generation of gas. Circulation in the liquid, however produced, has the same effect.

226. *Heat* applied to the bottom of a cell has this effect: it is probable that the heat adds slightly to the EMF as in § 194, but at all events it keeps it nearly constant by bringing fresh liquid to the plate. I have obtained a constant current from a bichromate cell, close up to exhaustion, by means of a small gas jet under it. The heat lowers the internal resistance, and in this way compensates for the gradual lowering of EMF due to the chemical change of the solution, and keeps the EMF up to full limit by preventing the so-called polarization due to the presence of exhausted liquid at the plate.

227. *Chutaux* and others have arranged the cells of a battery so as to permit the liquid to pass through them slowly from a reservoir above to one below: their cells are usually packed with sand, which gives a high internal resistance, and they exchange the receivers at intervals so as to allow the liquid to pass several times through the battery.

228. *The inclosed cells*, § 224, could be readily used in a similar

manner. If the outlet or vent-pipes (provided for emptying the cells and allowing gases to escape) were of proper length and bent over so as to enter the inlet or feeding pipe, the liquid would flow from one cell to another with very small difference of level, and if several cells were thus mounted in *series* they would unite their slightly-differing E M F. If connected together by caoutchouc tubing they might be at one level, and the liquid forced through them at any desired rate by the elevation of the reservoir.

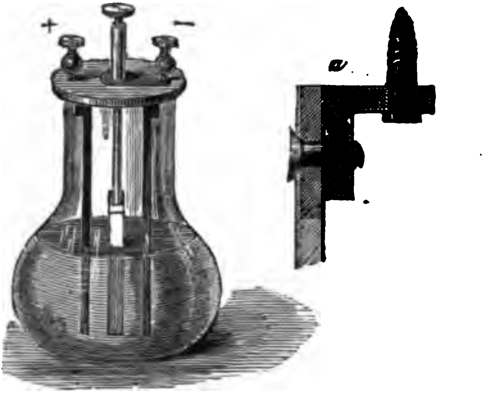
229. *Rotating carbon plates* have been used to attain the same result. The carbons are in the form of discs mounted on an axis with only the lower half in the liquid, so that the motion of the axis brings new carbon surface, carrying also a film of air, and also stirs the liquid.

230. *Pumping air* into the liquid is another mode of causing circulation, and though it does not add to the E M F it does prolong the action of the liquid by itself supplying the oxygen to the plate. This process was used in Byrne's pneumatic battery, § 219, and produced a very powerful current from small cells.

231. BICHROMATE SINGLE CELL.—This consists of two plates of carbon, with one of zinc between them, fitted so that it can be raised out of the liquid. Of late many of the shops have small bichromate cells without this fitting, the intention being to let the cells go on working to exhaustion; it is therefore desirable to warn readers against using such cells, which are most extravagant and unsatisfactory. Used for the purposes to which it is suited, the bichromate cell is one of the most useful; it furnishes a most powerful current for a very short time, it is therefore admirably adapted for short experiments with induction coils, as it gives a greater force than the nitric acid batteries, and has no unpleasant fumes, while it can be set aside for weeks and be ready for action at any instant. But for long-sustained action it is utterly useless, as its force fails very fast. The simple action of raising and lowering the zinc, however, instantly restores it for reasons explained § 225. Fig. 46 shows the usual construction.

The containing vessel is a glass bottle enlarged into a globe below; the object is merely to hold a larger quantity of liquid, and any form of vessel will answer. The essential part is the top which carries the plate; this is best made of ebonite, but hard baked wood saturated with paraffin will do; in the centre of this is screwed a projecting brass tube split at the top to grip the rod carrying the zinc which slides in it: the foot of this tube also passes through a plate of brass extending on one side of the cover to the negative binding-screw. This sliding part is often troublesome, as the surfaces tarnish and make bad contact; they should be well gilt to avoid this, and some attach an open spiral of wire to the lower part of the rod and to the tube, so as to make a fixed metallic circuit independent of the sliding one; others attach the binding-screw to the top of the sliding rod. It is desirable to form a screw-thread on the top of the tube, and fit to it a nut, by tightening which contact is improved, and the zinc firmly held up when not in action; also a square tube and rod are better than round ones, as they keep the zinc always parallel with the carbons. The zinc is commonly fixed to the rod by means of a screw on the end, but it is far better to solder them together. I was once greatly troubled with an irregular battery, which would not keep to its work, though I pulled it to pieces and set everything right, as it appeared, and after great trouble traced the whole fault to this point; acid had found its way into the thread of the screw and entirely destroyed the connection. The carbons are secured to the cover by means of two angle pieces or brackets of brass or iron, as shown (*a*, Fig. 46), and these brackets are connected to the + binding-screw. The connection is thus one of simple contact, and with a porous carbon it is common for acid to find its way up between the surfaces and destroy the contact. This may be entirely remedied by the plan described in § 222; and the upper part of the carbon being coppered the bracket may be soldered

FIG. 46.



to it, and perfect connection insured, and protected by a covering of paraffin.

It is impossible to estimate the cost of working this cell, because the local action in it is so great, and this being nearly constant while the zinc is immersed, or when frequently removed, its proportion to the work actually done will be less as this is greater—greatest, that is, when there is great resistance. For the average of working it is probable that the cost may be taken as ·2000, or half as much again as given in § 208.

A very convenient form of this cell is used as a battery and commutator combined, for such purposes as bells and other appliances requiring a momentary current; the zinc and its rod is supported by a spring, spiral or otherwise, and is pressed into the liquid when the current is required; on relieving the pressure the zinc leaves the liquid, and cuts off the current. The same form of cell is also used in apparatus for obtaining light, and for lighting gas. The zinc plate in these should be fixed parallel to the surface of the liquid so that a small motion will immerse it.

SLATER'S IRON CELL.—In almost all the forms of battery iron may be used in place of zinc for the dissolving metal, but owing to its lower electromotive force, and other practical reasons, it is seldom employed; however, Mr. Slater has introduced a form of cell in which iron as the negative metal is combined with the use of nitrates as the oxidizing agent, and which may be of use where it can be so placed that the fumes from it are not injurious, for though less than in other cases, these are still given off, and render it objectionable in a confined space. It cannot be used for such purposes as nitric acid cells are used for, but might be useful in factory work.

The construction is the same as the Bunsen, a block of carbon in a porous cell of large size, as 1000 fluid grains contain only 6·5 units of acid available. The solution is nitrate of soda, saturated at 100° Fahr., and 2 equivalents of sulphuric acid added for 1 of salt dissolved, which brings the specific gravity to about 1·568. On cooling, a quantity of sulphate of soda crystallizes out.

At starting, the outer cell is charged with water, to which is added a small proportion of the solution to render it conducting, and set up the action, which is then kept up by electrolysis and by endosmose, though it is to be observed that the liquid passes somewhat rapidly into the inner cell, the liquid in which stands at a considerably higher level than in the outer; the action is maintained by removing a portion of the inner liquid at times, and adding fresh solution, so that there is little waste. The power of this cell is considerable, and its cost ·1086 of a penny per unit.

232. IRON PERCHLORIDE.—This has been employed in batteries; its action consists in undergoing a reduction to ferrous chloride, and the object aimed at was the regeneration of this by absorbing oxygen from the air, so as to maintain an inexhaustible oxidant. It has the same drawback as the bichromate battery in rapid failure, and its force is also low: there are, however, cases in which such a combination might be useful, and it will form a single cell with iron as positive, and work to exhaustion if free acid enough is occasionally added and the excess of liquid removed.

Peroxide of iron might be employed for similar reasons, instead of and in the same way as the manganese peroxide, § 233, but it gives only just half the force of the latter.

233. PEROXIDE OF MANGANESE BATTERY.—Various peroxides have been employed to surround the negative plate and furnish the oxygen. Peroxide of lead is the most powerful of all, and consequently a battery in which this is used gives a very high electromotive force; but it is costly, and has never been used except experimentally, but it is the active agent in the *secondary* batteries made of lead plates. The peroxide of manganese was first used by De la Rive, many years ago, but the difficulties which soon present themselves to those who use it, limit its applications, though it has many good qualities, which have brought it into use, and it has been patented under the name of "Leclanché" cell. For cases requiring a large current, as in plating, or for magnets or coils, it is absolutely useless; for a small occasional current, on the other hand, as for ringing bells, household signals, &c., it is one of the most useful forms; though the statements made by sellers that the cell is calculated to work for "three years" is, of course, pure nonsense. Like every other form it can yield a current equivalent only to the quantity of material used in it, which will be exhausted in a greater or less time according to the work done. Its duration depends upon two things—the quantity of the excitant and the quantity of the manganese.

The work any manganese cell can do will probably be to furnish one unit of current for each 150 grains of manganese put in it.

The peroxide, or binoxide, of manganese is, on the atomic notation, $MnO_2 = 87$; two of these molecules enter into the reaction producing Mn_2O_3 sesquioxide of manganese, and O 1 atom of oxygen; therefore 87 of it by weight yields 8 of oxygen, and 1 unit of current; but this is the pure substance, while the commercial manganese contains often a large percentage of impurity, so that 100 is about the unit: in addition to this, as no solution occurs, the action takes place only on the surface of the particles into which the material is divided, and hence a considerable portion may escape action; it is therefore impossible to fix upon any quantity as the electric unit; it may range from 100 to 200 grains or more. According to Leclanché, to 100 parts of peroxide and 100 of sal-ammoniac, there are 50 parts of zinc dissolved. The peroxide is a good conductor; the resulting sesquioxide is not a conductor (and the same is the case with the corresponding lead oxides), hence the action tends to diminish: and a main object must be to spread the material in as thin a film as possible over a large area of conducting surface. This is most readily accomplished by crushing carbon into various sizes, from a pea down, and packing the larger pieces tightly in a porous jar, in layers, so that the particles are in firm contact among themselves, and with a plate or bar of carbon which forms the main plate or conductor; the finer grains should be mixed with three times their bulk of manganese also in fine grains and sifted in among the network of large pieces: the fine powder has to be sifted out, because it resists the penetration of the liquid. The result of this arrangement is to expose a very large surface, which compensates for the inherent slowness of the action itself, and reduces the internal resistance.

A very small surface of zinc is sufficient, and it generally is one or two small cast rods or rolled strips suspended in the outer vessel.

This is the usual arrangement, but it is far better to reverse it, and put the zinc inside the porous vessel, making the battery up as described § 224 with the manganese added as above.

The Leclanché cell is now constructed with a conglomerate or solidified block of carbon and manganese, which can be replaced by new when exhausted. This dispenses with the use of the porous cell.

234. THE EXCITANT.—Either common salt or sal-ammoniac is employed, though others will answer. It may at first sight seem difficult to say why sal-ammoniac at *6d.* per lb. should be used if common salt at 3 lb. per penny will answer; but as a couple of ounces of the chloride of ammonium will charge a cell such as the ordinary Leclanché, and do the amount of work for which alone it is properly fitted for several months, the question of economy dwindles to a very small matter against the higher electromotive force the ammonium chloride gives over that furnished by the sodium chloride. The reason for this higher electromotive force is, that soda displaces ammonia from its

salts, and, of course, in doing so loses force; therefore, when they are decomposed the sodium salt has less to yield. In the one case, caustic soda is generated within the porous cell; in the other, ammonia is set free and given off, while the soda remaining exerts a counter-electromotive force. The force is greatly increased by occasionally adding a little acid to the manganese cell to neutralize the alkali.

Calomel has been proposed as an addition to the manganese cell in the expectation that the mercury would be set free and ammonium chloride produced. This reaction would not occur, as ammonia, chlorine, and mercury are capable of uniting together in several combinations: but it is possible that the reaction may give steadiness and higher E M F to the cell, but whether the gain is equivalent to the cost is doubtful.

I have found the electromotive force at first starting to be with—

Sal-ammoniac	1·543 volts.
Sulphate of ammonia	1·493 „
Common salt	1·285 „

Ammonium chloride forms double salts with zinc chloride, and also with hydrated zinc oxide, and the latter compound appears in the form of crystals upon the zinc and porous cells. The crystals have the formula $Zn\,O, H_2\,O, N\,H_4\,Cl$. As they obstruct the action they should be removed with warm water containing a little acid, but they do not form so readily if a half-saturated solution is used.

The cost of the manganese cell is probably ·25 of a penny per unit for materials, but this is the least consideration, because the trouble of charging is the real cost.

235. The manganese cells are troublesome, because the porous cells choke up and are broken by the formation of the double salts mentioned, and especially because the ammonium chloride finds its way between the carbon and the lead cap usually cast upon the carbon as a connection, and produces a film of non-conducting matter between them. But they are very largely used in telegraphy and for electric bells.

For many purposes a cell constructed with crushed carbon as described will serve without the addition of manganese, especially if the cell is made rather high, the solution rising only half-way up it, and free access of air allowed to the carbon: but this is available for only very short demands upon its force.

236. *Sulphate of lead* has often been used in batteries, and a patent was taken out for using it in a series of cups of copper fixed

on a copper rod. But the electromotive force is low, though fairly constant, and the cost ·1738 of a penny, subject to any residuary value. It can be used with sulphate of zinc solution, or with common salt, which, however, carries lead to the zinc plate, and undergoes a curious reaction, by which sodium appears to react upon part of the lead sulphate and generate a sulphide, which ultimately gives off sulphuretted hydrogen.

237. THE SULPHATE OF MERCURY CELL.—This, which is called from its inventor, the Marie-Davy Cell, is of use only in circumstances requiring a small intermittent current of great force; it is a zinc and carbon pair, the latter of which extends to the bottom of the vessel and dips into a mass of the sulphate. The vessel is then charged with water, which dissolves a small portion of the salt slowly, and this sustains the action, the acid radical acting on the zinc, the mercury depositing on the carbon, from which it falls and collects as metal at the bottom. The action can, therefore, only be sustained at the slow rate at which the salt enters into solution. It has gone out of use because the manganese cells answer the practical purposes to which it is adapted, and the chloride of silver is better for scientific uses.

238. CLARK'S MERCURY CELL. — This was devised by Mr. Latimer Clark, not as a working cell, but as a standard of electromotive force, to compare with other cells by means of condensers or electroscopes, it having a constant electromotive force of volt 1·457. It consists of a layer of pure mercury as the negative plate, connected by means of a platinum wire in a glass tube. On this is laid a paste of mercurous sulphate, which has been boiled in a thoroughly saturated solution of zinc sulphate; the positive element is a plate of pure zinc resting on the paste. Mercurous sulphate, Hg_2SO_4, can be made by heating 1 part of mercury in 1½ of oil of vitriol, taking care that the heat does not rise to the boiling-point, which would produce mercuric sulphate $HgSO_4$. The mass is to be washed with cold water as long as an acid reaction is shown. If any mercuric sulphate is present, a yellow colour will be produced, and the substance should be rejected. In fitting up the cell, it should be warmed with the mercury in it, and the paste inserted after boiling to expel air. The zinc is then placed in it, and melted paraffin poured on to exclude air. A cell intended to serve as a standard of E M F should never be allowed to pass a current; with this precaution it will be fairly constant. Heat decreases the E M F about ·06 per cent. per degree Cent. for about 10° C. above or below 15°. Below this and towards 0° C. the E M F increases ·08 per degree.

239. CHLORIDE OF SILVER CELL.—This is a wire or plate of silver, upon which chloride of silver has been melted as a coating of "horn silver" in a solution of zinc chloride, and is much used to work small pocket coils for medical purposes.

The freshly-dried chloride of silver can be fused over a gas-burner in a porcelain dish or crucible, and the silver dipped into it; after it has attained the proper heat to cause a film to adhere it is removed, and after cooling a little, re-dipped till a sufficient coating has adhered. This is usually wrapped in blotting-paper or other material which will absorb liquid, and a zinc plate pressed against each side. The plates are often attached to a cap, which can screw on the top of an ebonite case. They are to be dipped occasionally in a weak solution of chloride of zinc to remove excess formed by the reaction which produces that salt.

But the chloride may be used as a powder, in the same way as the sulphate of mercury in the Marie-Davy, or it may be mixed with powdered graphite, and used in a porous cell with a plate of carbon. As chloride of silver is produced on the large scale in refining and other metallurgical operations, and has to be reduced for the sake of its metal, it would appear that where it can be obtained at a trifle less than the value of the silver it contains, a very economical and powerful battery might be thus produced. The reduced silver can be dissolved in nitric acid, and the chloride reproduced. It might be revivified by a reverse current, in which case this battery would be an excellent secondary battery; but, as in many cases of electrolysis of chlorides, a considerable quantity of oxychloride is produced, which is not readily reduced again.

240. De La Rue's cells are composed of a cylinder of chloride 2¼ inches long and ⅓ of an inch thick, cast upon a flattened silver wire, and wrapped in a tube of parchment paper. The wire passes through a stopper of paraffin wax (which also carries a small zinc rod) inserted in a test-tube 1 inch in diameter and 5½ inches long: the solution is ammonium chloride 200 grains to the pint of water. The E M F is 1·065 volts, and the resistance 3 to 4 ohms, increasing as oxychloride forms on the zinc sometimes to 30 or 40 ohms. This deposit can be removed by dipping in dilute hydrochloric acid. The cells are mounted in racks like test-tube stands, and Mr. Warren de la Rue possesses a collection of 14,400 such cells, with which he has performed many interesting experiments at the Royal Institution, mentioned § 101, p. 85.

241. *Zinc in alkali.*—In all forms so far considered acids have been employed as solvents of the positive metal: but alkalies

may be employed with metals soluble in them; thus zinc, lead, and tin are soluble in caustic soda and potash, producing materials useful in dyeing and other arts. Copper is soluble in ammonia, producing a compound (cuprammonium) which has the property of dissolving cellulose. Caustic alkalies or their carbonates separated from acids by porous cells generate E M F by their reaction, even with plates of similar metal, as platinum, and this may be added to the force arising from their separate relations to different metals. The only objection to alkalies is that they absorb carbonic acid from the air.

Caustic soda will replace the acid in a Daniell's cell, giving a higher E M F. The two liquids react upon each other and produce a precipitate, so that an open-grained porous cell is desirable, or one can be made up advantageously of several thicknesses of parchment paper. The precipitate is itself electrolysed, and so transmits the action.

242. This principle is applicable in a variety of cases: for instance, a powerful cell can be made with nitrate of silver in a porous cell and chloride of zinc in the outer cell. The chloride of silver fills the pores and stops endosmose, while, being electrolysable, it does not stop the current. Such a cell resembles the Daniell with a silver salt replacing the copper sulphate, and the silver is deposited on the negative plate.

243. *Bennett's battery* is a simple apparatus, well adapted to purposes similar to those for which the Leclanché is used. The outer cell is a cylinder of iron, and for rough purposes preserved meat tins have been used. The porous cell being inserted, the space is packed with coarse iron borings, which give a large surface of the character best adapted to giving off hydrogen. The excitant is caustic soda or potash, in which the zinc can be suspended from the cover. The electromotive force is variously stated as from volt 1·15 to 1·3. My own experiments give 1·259 when first set up. If worked on short circuit, the force soon lowers to less than half, and recovers after resting. It is a cheap battery to work, as the soda solution is easily prepared by boiling 1 lb. carbonate of soda (common washing soda) in 4 pints of water with 6 ounces of quicklime reduced to a cream with part of the water. The boiling should be effected in an iron pot not tinned, and continued as long as the clear solution effervesces on addition of acid. It can be separated from the carbonate of lime by settlement and pouring off, and, if desired, boiled down to dryness for keeping. The solution of potash gives a higher force than soda, but is more expensive. The zinc does not require amalgamation, and may be recovered in the form of a white oxide suitable for paint.

244. **Earth Battery.**—A plate of zinc and one of copper, or a bag of coke buried a little apart in moist earth, has been used under the name of an earth battery, for driving clocks. This is its only use, and as it has a low force and high resistance, all that can be said in its favour is that, once mounted, it is out of the way and requires no attention; but any ordinary small cell will do as much work. It is not possible to have several in series, but the action can be increased by placing the zinc plate under a stable or in other position where saline liquids can penetrate. Some have constructed an earth battery by using the lead water-pipe as one plate and the iron gas-mains as the other; but this means injury to the latter, and that injury is likely to occur at the nearest possible point to the user.

245. There are many other forms of the galvanic cell; many useless; most mere modifications or forms of those described. Others have great scientific interest, but do not come within the objects of the present work. Such is Grove's Gas Cell, in which oxygen and hydrogen are in contact with platinum plates dipping in an acid solution which separates the gases, and act the part of the metals while recombining as water: this is, in fact, the voltameter reversed, and a voltameter with separate receptacles whose plates project above the liquid will, when the decomposing current is cut off, act in turn as an electromotor and give up, in the form of a galvanic current, the energy employed in setting the gases free. There are very many forms of this principle, such as those which act by absorbing oxygen from the air; of these, one of the most interesting is that proposed by Messrs. Gladstone and Tribe, who have made so much use of the electrolytic action upon substances of a copper-zinc couple, formed by zinc on which pulverulent copper is precipitated from the sulphate. When silver and copper are connected in a solution of copper nitrate well aërated, the copper dissolves and cupreous oxide is deposited on the silver; a similar action occurs in a solution of zinc chloride with zinc and copper. The negative metal is arranged as a tray near the surface, perforated in many places, and containing also crumpled masses of the metal in foil rising above the liquid to facilitate absorption of oxygen. Such means of absorbing oxygen from the air may be applied to many reactions, and offer good promise of utility, especially on a large scale. In fact, as before observed, any chemical reaction which occurs between conducting substances may be utilized to generate electric currents. This fact disposes of the old theory that E M F is the result of the mere contact of different metals (or different bodies, as in the recently

revived form of the contact theory), for the force is set up where there are no different metals in contact, and generally the chemical affinity alone supplies and measures exactly the electromotive force. This is also shown by the fact that in a copper and iron pair iron is the positive metal in acids because it dissolves; but in sulphide of potassium, which dissolves copper, the copper is the positive metal. This difference was very prettily applied by Mr. Fleming in attacking the contact theory, by arranging cells containing nitric acid alternately with cells containing sodium pentasulphide, and connected alternately with bent strips of lead and copper; in the acid lead is positive to copper, and in the sulphide it is negative; so that a battery is composed in which there is no contact of metals, and the terminal cells contain the same metal, which, being copper, gives also no contact of dissimilar metals when the copper conductors from a galvanometer are connected. The combination is said to have one-fourth the force of a similar number of Daniell cells. It is not available for practical purposes, but has much theoretical and scientific interest.

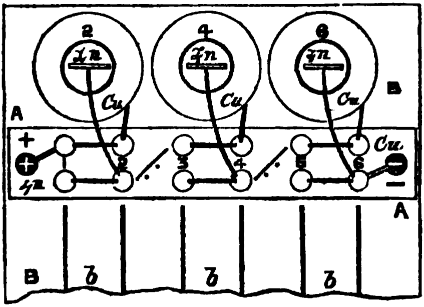
246. Batteries are being largely superseded by dynamo-machines, as a matter of economy. The principles indicated in this chapter may show manufacturers and others that in many cases economy will tend to the opposite process. As all chemical reactions which occur spontaneously, liberate energy, which is usually wasted in practice, but might readily be converted in many cases into electrical work, it is evident that this "waste product" may be utilized. The production of metallic paints, solutions for dyeing purposes and many other chemical products might well be combined with the production of electric currents to bring about other reactions which now necessitate the supply of external energy, usually effected by means of heat.

247. ARRANGEMENT OF BATTERIES.—The laws which govern the mode of arrangement of a number of cells, in order to effect most work, will be found in the chapters on Current and E M F.

In joining cells, care should be taken not to waste energy in the connections; all contacts should be as large as possible, and perfectly clean. This is often neglected in mounting batteries, particularly in Grove's cells, where the platinum is bent over and screwed to the next zinc; in all such cases the metal should be fixed to a thick plate of brass, so as to screw firmly to the zinc.

The connecting wires should be of good size, and should be wound in a spiral in order to give some elasticity. Care should be taken that the troughs, boards, &c., are quite dry, and that there has been no leakage or creeping of liquids from the cells, which causes short circuits and great loss of power. To avoid this, the jars should not stand directly upon a board; but a good plan is to place two strips of varnished glass edgeways along the troughs or stands, for the cells to be placed on.

FIG. 47.



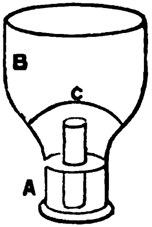
248. A plan I have found very convenient is shown Fig. 47. B is a wooden base across which are secured strips *b b* of glass. A is a bar of wood raised to the suitable height, in which are sunk holes, marked 1–6, each pair intended for the connections of one cell, while one row is for the whole of the zincs, and the other for the positive poles of the cells; each row is permanently connected to a binding-screw + and − by wires under the wood let into the last hole of the row: the holes are to serve as mercury cups and should be ¾ inch deep: pieces of copper wire, bent over at each end, bridge over and connect the cups as desired, and enable the connections to be made as desired; they are shown connected two cells in multiple arc and in series of three. The cells are placed 3 on each side of the commutator bar A. The outer cells *Cu* (as Daniells) have wires which connect them to their proper cups, as have the zincs. When the battery is out of use, the zincs can be lifted out and placed in a jar of water, with corks on the ends of their wires; the porous cells can be also removed and stood in a vessel containing the same liquid as themselves; the copper cells remain in their place, with covers on, and the whole is again mounted in a minute when required. It is evident that, if the battery is to be kept somewhere inconvenient of access during experiments, the bar A may serve only to connect the cells, and wires can be led from the cups to a second similar bar elsewhere which will serve only as the commutator. This plan is also convenient

when B is the bottom of a box in which the whole battery is inclosed; then the second bar A can be attached to the outside of this box and be the only part exposed. A should be removable for convenience of cleaning.

249. This latter mode also is suitable with the closed nitric acid cells described elsewhere; these should have a rather long upright vent-tube rising straight up from the cell; a tray can then be placed over the whole of the battery (or one to each cell), with holes in the bottom for the tubes to pass through, the tray containing lime in lumps or powder to absorb the fumes.

Another mode of effecting this absorption of fumes is shown Fig. 48. B is a bottle cut off (or a closed flask may be used), with its neck fitted with a cork carrying a tube to be placed over the vent-tube of the cell; a tray of perforated lead C in the bottle supports lumps of lime or chalk.

Fig. 48.



All the wood should be baked, and then boiled in paraffin, of which a good coat should remain on the surfaces, and the copper wires should be well protected with varnish except at the ends dipping in the mercury, which should be amalgamated and have corks stuck on them when out of use. It should be remembered that when a strong current passes through a porous material, it carries the liquid with it from the zinc cell, § 186; space must therefore be allowed in the carbon cell, or otherwise the liquid will be apt to overflow.

250. WORK AND CONSTANCY OF CELLS.—Table IV. gives a series of experiments on cells, all in like conditions, with plates

TABLE IV.—WORK AND CONSTANCY OF CELLS.

	Minutes.				Hours.	
	1.	5.	15.	30.	1.	2.
Copper-zinc	5·2	4·2	3·8	3·5	3·2	3·
Iron	2·9	2·	1·7			
Lead	4·9	0·5				
Platinized silver	17·7	13·7	11·	9·	7·3	6·4
Daniell's	6·8	6·9	7·2	..	7·1	7·
Bunsen's nitric acid	12·	..	..	13·	13·1	12·
Slater's	7·8	7·3	7·	6·8	5·9	4·2
Bichromate	7·3	7·8	7·3	7·	4·	2·1
" Single cell	12·	10·6	9·4	8·4	3·8	1·1

2 × 1 inches, set 1 inch apart, and with no external resistance, except that of a tangent galvanometer. The currents are given in chemics, and therefore are proportional. In the cells with porous division, it will be seen the current rises at first as the liquids soak in; in these cells, also, the current is reduced by the resistance of this division as compared with the single liquid cells.

251. Table V. (p. 170) contains a list of the principal substances used in electrical operations, arranged to accord with the unit of "quantity" and of "current" used in this work, and explained § 159, showing the amount of each required to act with the unit of electric quantity or current. The weight (col. IV.) allows for the ordinary impurities always present in commercial articles, and applies to good commercial materials not intentionally adulterated. The price (col. VI.) is such as the substances can be obtained at in the ordinary way (with the exception of the silver salts), and where a different price is paid the user can readily apply a correction to the unit cost (col. VII.) in any calculations.

Under the French system of weights and measures such a table would be far more useful than our wretched confusion allows it to be, as the figures obtained for the small units would apply equally to the largest amounts used in practice, while in the English system one calculation is needed to convert grains into pounds, and then another to ascertain the cost of these larger quantities.

252. COST OF BATTERY WORKING.—The value and mode of using the table of costs will be seen in the example § 197. These costs are those of unit *quantity*. But to compare the real value of different cells we must take into account the *energy* of the combination as well. This subject will be explained hereafter, but the required information is given by dividing the cost per unit quantity by the E M F in volts, which gives the cost of 1 equivolt of electric energy 4673 ft.-lbs. The unit in practical use is the volt-ampère or joulad, and I have shown the value in both terms in Table VI. (p. 171). Another point has to be considered in deciding upon economy, the relative internal resistances: thus while lines 1 and 5 show nearly equal cost for energy, the nitric acid cell gives the energy in a useful form, while the copper-zinc would require 7 cells in series to equal 1 Grove, and would waste the greater part of the energy within the cells, instead of giving it up for the external work.

The work in foot-pounds done by 1 grain of zinc in any combination is given by multiplying 4673 by the E M F in volts and dividing by 32·6, the equivalent of zinc, or more

TABLE V.—SUBSTANCES USED IN ELECTRIC WORKING.

	I. Name.	II. Atomic Weight.	III. Valency.	IV. Commercial Equivalent.	V. Equivalents per lb.	VI. Price per lb.		VII. Cost per unit.
				grains.		s.	d.	d.
1.	Acid hydrochloric	36·5	1	113	61	0	2	·0326
	„ „ fl. measure	..	..	85				
2.	„ nitric	63	1	96	73	0	8	·1096
	„ „ fl. measure ..	..	..	69				
3.	„ sulphuric	98	2	50	140	0	1½	·0107
	„ „ fl. measure	..	..	28				
4.	Ammonia	17	1	48	148	0	9	·0608
	„ fl. measure ..	..	..	55				
5.	Ammonium chloride ..	53·5	1	56	125	0	6	·0480
6.	„ sulphate ..	132	2	70	100	0	3	·0300
7.	Calcium chromate	349	2	60	116	0	7	·0604
8.	Copper	63·5	2	33	212	1	0	·0566
9.	„ sulphate	249·5	2	126	55	0	5	·0900
10.	Iron	56	2	30	232	0	2	·0086
11.	Lead sulphate	303	2	159	44	0	6	·1363
12.	Manganese peroxide ..	87	..	100	70	0	4	·0572
13.	Mercury	200	2	100	70	4	0	·6857
14.	Mercuric sulphate	296	2	150	46	4	0	1·0285
15.	Potassium cyanide	65	1	100	70	3	0	·5144
16.	„ bichromate ..	295	2	300	23	0	10	·4290
17.	„ „ ..	295	2	50	140	0	10	·0715
18.	Silver	108	1	108	64	135	6	16·4062
19.	„ chloride	143·5	1	144	48	80	0	20·0000
20.	„ cyanide	134	1	134	52	80	0	18·5000
21.	„ nitrate	170	1	172	40	60	0	17·6914
22.	Sodium chloride	585	1	60	116	0	0¼	·0043
23.	„ nitrate	85	1	87	80	0	2	·0249
24.	Zinc	65	2	34	201	0	4	·0195
25.	„ amalgamated	..	..	..	..	0	6	·0292
26.	„ sulphate	287	2	148	47	0	3	·0634
27.	„ and H_2SO_4 cell ..	..	..	365	..	..		·0438

1. HYDROCHLORIC ACID.—Variable in strength; good quality is of sp. gr. 1·16, and contains about 32 per cent. HCl.

2. NITRIC ACID.—This varies greatly through the various qualities sold as nitric acid, aquafortis—double and single, dipping acid, &c. The highest strength has a sp. gr. 1·5; ordinary good commercial is about 1·390 to 1·420, and contains from 65 to 75 per cent. HNO_3. I have taken the acid at 1·400, and as equal to 70 per cent.

3. SULPHURIC ACID.—This means concentrated oil of vitriol, sp. gr. 1·845, which is obtainable nearly pure.

4. AMMONIA, sp. gr. ·880, contains 36 per cent. NH_3.

15. POTASSIUM CYANIDE.—This is the white, which varies in quality from about 50 per cent. to 75, the highest which can be made, as the process involves the production of a proportion of cyanate. The quality is taken as 65 per cent.

18 to 20.—The SILVER SALTS are calculated as if made, allowing for labour, the silver being taken at 6s. per ounce troy. The cyanide is supposed to be simply precipitated and washed, not dried, and reckoned at 5s. per ounce. The chloride has an extra charge on it to pay for separation and fusion for use in batteries, and is therefore at the same price as the cyanide. The chloride ought to be obtainable 3d. per unit cheaper, in fact at its worth in silver—that is, at 68s. per lb.—as it is a product in silver working, and has to be reduced for the sake of its metal. Nitrate of silver may be bought at 3s. 9d. per ounce, the price in the table. The cyanide should never be purchased, as it ought not to be dried.

TABLE VI.—COST OF BATTERY WORKING.

Section.	Name of Cell.	EMF Volts.	Cost in Pence.		
			Per unit Current.	Per Equi-volt.	Per 1000 Joulads.
173	Copper-zinc	0·28	0·0438	0·1564	0·0247
176	Smee	0·50	0·0438	0·0876	0·0138
182	„ odds and ends	0·50	0·0284	0·0568	0·0090
187	Daniell	1·08	0·0584	0·0543	0·0086
204	Nitric acid, 1st stage	1·8	0·2590	0·1439	0·0227
205	„ „ 2nd stage	1·55	0·1025	0·0621	0·0104
207	„ and hydrochloric acid ..	1·85	0·1360	0·0735	0·0116
208	Bichromate of potash	2·	0·1320	0·0660	0·0104
211	„ and hydrochloric acid	2·1	0·1668	0·0794	0 0125
231	„ single cell	1·8	0·2000	0·1111	0·0175
233	Manganese	1·5	0·2494	0·1663	0·0263
236	Lead sulphate	·57	0·1738	0·3049	0·0481
237	Sulphate of mercury	1·52	0·5337	0·3502	0·0552
239	Silver chloride	1·2	0·2000	0·1671	0·0263
	„ „ per Table V...	1·2	3·6230	3 0192	0·4763

simply by making this division at first and multiplying 143·35 by the EMF.

253. The question is frequently asked, What is the best battery? The foregoing description will show that no answer is possible, for no such thing exists; each form has qualities adapted to particular purposes; each has also its defects, therefore selection must be made according to the intended work. The following classification will assist in the selection.

TABLE VII.—SUITABILITY OF CELLS.

1. NAMES OF BATTERIES.

1. Smee.
2. Daniell.
3. Nitric acid.
4. Bichromate.
5. „ with HCl.
6. „ Single cell.
7. Bennet's soda.
8. Manganese.
9. Mercury sulphate.
10. Silver chloride.
11. Magneto-electric machines.

2. USES CELLS ARE SUITED FOR.—*Large Currents.*—

Continuous.

Electro-deposition	2, 1, 3, 5
Gilding	3, 5
Silvering	2, 1
Electro-magnets	6, 3, 1, 2
Electric light	3, 5

Temporary.

Induction coils	6, 3, 4, 1
Medical coils	6, 1, 4
„ „ pocket	10, 9
„ „ continuous current	8, 9, 1

Small Currents and High Resistance.

General telegraphs	2, 8, 1, 11

Occasional.

Domestic bells and telegraphs	7, 8, 10, 1
Exploding fuzes	11, 8
Testing resistances, &c.	6, 4, 7, 8

254. SECONDARY BATTERIES.—Most operations are reversible: a falling weight will drive clockwork, and the clockwork will raise the weight. So in chemical action oxygen and hydrogen combine and give up energy while forming water, and an equal quantity of energy applied as an electric current, decomposes the water (unburns it, in fact) and separates the gases. In this action the energy connected to one equivalent H 1 grain, O 8 = water 9, is measurable as 6840 foot-lbs., and the electric conditions represent an E M F of 1·5 volt. In like manner, every chemical action which, giving up energy, constitutes a battery or electric generator, can be reversed by means of a superior E M F, when it receives and stores up energy. Such batteries are therefore called *accumulators*; they are also called *polarization batteries* because the E M F found to exist upon pairs of plates in an electrolysed solution was attributed originally to some electric polarization, whereas it is simply the reaction of the chemical agents collected upon the plates.

255. In the Smee cell we have zinc displacing hydrogen as shown Fig. 42, p. 118: let us reverse the direction of the force, as shown by the arrows, adding also a molecule of water H_2O which is to be decomposed; then we have $Zn\,SO_4 + H_2O$ which becomes changed into $Zn + SO_4H_2 + O$; the zinc is separated, sulphuric acid formed, and oxygen set free, provided there is nothing for it to unite with.

256. In the Daniell cell we have zinc displacing copper from its sulphate, $CuSO_4 + Zn$ becoming $Zn\,SO_4 + Cu$, with generation of an E M F 1·079. By the application of superior force we can reverse this process, and by electrolysis of zinc sulphate from a copper anode convert it into copper sulphate

and deposited zinc. Hence a Daniell cell, when exhausted, can have a reverse current from a dynamo machine passed through it, and be fresh charged. This is one of the forms of "accumulators" which has been proposed, but is not practicable for reasons given § 295.

257. Reverting to the conditions of § 255, we have oxygen freed, and this is wasted energy: it may be saved by collecting the oxygen and using a plate in such manner as to form a gas battery which will gradually absorb the oxygen; or we may use a plate of such material as will absorb the oxygen chemically; such an electrode exists in the ordinary manganese cell, § 233, for the exhausted sesquioxide of manganese will take up the oxygen again and reform the peroxide. Iron or oxide of iron will also act in this manner. Lead is, however, found most suitable, because in the presence of sulphuric acid lead does not pass into solution from the anode, but forms peroxide, and this being a good conductor constitutes (§ 233) a very powerful negative element or battery plate.

258. Zinc, in the presence of acids or alkalies or of most metallic salts, sets up spontaneous action; therefore the next step towards an ideal accumulator is to substitute some metal not so acted upon; palladium has the property of absorbing 900 times its volume of hydrogen, forming with it a true alloy in which hydrogen apparently becomes a perfect solid metal, and conducts electricity: but for the cost of palladium this would be a valuable electrode. Experiment has shown that lead is the best available metal, and we thus come to two plates of lead, with a solution of sulphuric acid between them, in which the decomposition of water is produced by electrolysis, the oxygen forming peroxide of lead, while the hydrogen is partly occluded in the porous lead surface, and partly employed in reducing pure lead from previously formed compounds.

259. A slight review may now be useful in fixing in the mind the principles involved and the relations between "primary" and "secondary" batteries. In § 148 we have seen that the electromotive force originates in the attraction of the zinc plate for the sulphuric radical of the acid, and in § 202 we have seen that the attraction of oxygen, &c., at the negative or collecting plate, increases the force. Generalizing this by the explanations in § 158, and by the aid of Fig. 42, p. 118, we see that there exists an attraction between the + plate and the − radical or ion of the electrolyte, and between the − plate and the + radical. These + and − properties and their consequent attractions may be inherent in the substances, or may be pro-

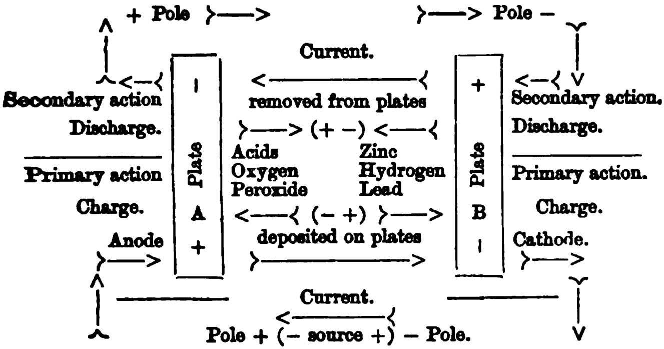
duced temporarily by means of electric energy. In the ordinary battery the superior + quality of the zinc sets up the condition of polarization and renders the other plate — in condition and polar order and attractive power, *although its own nature is + as related to the acid*, but + in a lower degree than zinc is.

260. If then we use two plates equally + by nature, two zinc, two copper, two platinum, we have no polarizing force present: but if by any means we can set up differential attractions at the plates, the force comes into existence. If we insert an electric source in the external circuit, we polarize the two plates in opposite directions, and give them this differential attraction for the ions of the electrolyte, to an extent depending on the E M F available; that is on the difference of potential we can set up between the plates. Again, if we modify the plates themselves by coating them with different substances the same effect is produced. If one of the platinum plates is lifted and exposed to the air its attraction for hydrogen is increased by the film of oxygen absorbed.

261. If we pass an electric current through the two platinum plates in acid, we coat the plates, one with a film of hydrogen, and the other with a film of oxygen; these two films now become the active agents, and their attraction for each other, reacting across the chain of intermediate molecules of the electrolyte, sets up the electric polarization. Precisely the same result follows from the presence at the two plates of any other substances having affinity for each other, a condition necessarily set up by any action of electrolytic decomposition. Thus with lead plates, the hydrogen reduces any oxide and is partially occluded in the lead, producing a + plate of lead or hydrogen representing the zinc of the ordinary batteries; the oxygen produces peroxide of lead, representing the nitric acid of the Grove, or other powerful oxidant.

262. It is important at this stage to avoid some probable confusion about *poles* and *plates*, the more especially because Dr. O. Lodge in his valuable series of articles on accumulators in the *Engineer* has contributed to this confusion by using the term + *plate* for that connected to the + pole of the source while charging, and which becomes the + pole of the battery when discharging. But to obtain a clear idea of the relations of the secondary and primary battery the same terms must be used in the same sense, and the word *plate* in the battery and its character as + or — refers exclusively to its relation to the electrolyte, and to direction of the current *within the battery*.

The reader should therefore refer to Fig. 42, p. 118, and compare it with the following scheme of arrangement.



263. The plates A B are shown as alternately + and − according as they are receiving current from the source, as shown in the lower half of the diagram, or discharging current, as shown in the upper half. In either case that *plate* is + *from which the current passes to the liquid* as shown by the long arrows at the ends of the plate.

Considered as charging from the source, below, A becomes +, therefore the electrolyte (− +) turns its negative ions towards it, and this class of radicals or ions is either deposited on the plate, as shown by the short arrows, or if the plate is soluble, as zinc in a battery or copper in a depositing cell, it combines with those ions: the reverse action occurs at the − plate B where the + radicals adjoining it are deposited.

Considered as discharging, B becomes the + plate by virtue of the presence there of the + ions which attract the − ions of the electrolyte, as in the ordinary battery.

264. It should be observed that if such a cell is connected to the source, and an external circuit is also connected just as shown, the plate A becomes a constant + *pole* to this external circuit: but a very complicated set of conditions would arise: in fact the cell and the outer circuit would be derived circuits to the source, and it would depend upon relative forces and resistances what course the current would take; no current would enter the cell unless the conditions were such that the difference of potential set up between the plates A B exceeded the E M F the cell itself could generate, therefore if the external circuit were one of small resistance, the current might

altogether pass to it: if the external circuit were broken, the cell might now receive charge from the source, and on the circuit being closed the source and the cell might act together in sending current to it. In this way a secondary cell would act as a true accumulator, would in fact fulfil the same functions as a fly-wheel fulfils in mechanism. This is probably the true use to which secondary batteries will be mainly applied. But in most cases automatic commutators would be required to vary the connections to suit the changing conditions.

265. History.—The reverse current arising from plates of the same metal which had been used in a voltameter was first observed in 1801 by a French chemist, Gautherot. The same observation was made in 1803 in Germany by Ritter, who endeavoured to utilize the reaction: he made a Volta's pile of plates of gold, separated by pieces of cloth moistened with acid, and subjected to the action of an ordinary Volta's pile of sufficient number of plates to send current through. The first theory of the action was, naturally, that some of the supposed electric fluid was soaked up by the plates; that in fact it was an action of surfaces receiving charge, and that the secondary pile was in fact strictly analogous in its actions to a condenser.

The chemists, and notably Becquerel, soon traced the action by means of saline solutions to the presence of acid and alkali at the opposite plates, and in due time the discovery of Grove's gas battery convinced the scientific world that the return current and "counter-electromotive force" were not due to an accumulation or storage of *electricity*, but to the presence of the substances having chemical affinities to each other, derived from the previous decomposition: that the counter-current was in fact originated on precisely the same principles as those of the ordinary galvanic cell: it was merely a different mode of charging a cell with its active ingredients.

266. The subject was studied by many, and nearly everything that is known even now, was discovered long ago; but it was simply a matter of scientific interest and theory with the possibility of some very limited applications. Among these Mr. Cromwell F. Varley employed a series of zinc and carbon plates mercurialized (in fact the Marie-Davy cell, § 237, reversed) to take a slow small charge, and deliver it up in a short powerful current for transmitting time signals in connection with the Post Office. His cells consisted of two carbon plates standing in troughs of mercury, with sulphuric acid 1 to 4 of water saturated with zinc sulphate: 20 cells slowly charged from 150 Daniells of high resistance gave an arc of ½ to ¼ inch for 20 minutes.

267. In 1859 Gaston Planté found that the best effect was produced by two sheets of lead in dilute sulphuric acid: he worked out a system of formation by which he greatly increased the capacity of the plates, and published to the world a number of highly interesting scientific results obtained by a great series of his cells with the aid of subsidiary appliances for converting series into multiple arc, and with condenser plates charged from the accumulators, by means of which the energy derived from a couple of Bunsen cells was enabled to produce effects which would have required thousands of such cells in series to produce. M. Planté studied the subject exhaustively, discovered pretty well all there is to know about lead secondary batteries, and published it to the world. He is a striking instance of a man doing thoroughly good work, and doing it with little profit, while others, taking up his labours, have patented every imaginable variation in the form and arrangement of his battery, and obtained in some cases large sums of money therefrom. But Planté's name will be associated with the secondary battery when these are all forgotten: and that the more quickly, if it proves, as will probably be the case, that the Planté battery pure and simple is superior to all these modifications.

268. In 1879 Messrs. Houston and Thompson proposed to use a gravity form of the Daniell cell for electric storage, but it was in May 1881 that public attention was really drawn to the subject by a letter published in the *Times* by Sir W. Thomson, announcing his possession of a "marvellous box of electricity," in which "a million foot-pounds of energy" had travelled from Paris to Glasgow, and which box was stated to be the "practical fruition" of electric storage, and was to do "for the electric light what a water cistern in a house does for an inconstant water supply." The public and the general press, ignorant of the fact that the large sounding million foot-pounds only represented the potential energy of about 1½ ounces of coal or the energy developed by an ordinary steam engine with 1 lb. of coal, became greatly excited, and, in a short time, the million foot-pounds of energy was duly converted into a million pounds sterling of capital to be obtained from the public; but what practical value may be the result can at present be expressed only by the algebraic symbol x, as usually employed.

269. The wonderful box of electricity consisted of lead plates coated with a paste of red oxide of lead, minium, held to the surface by means of a wrapping of felt. It was in fact a Planté battery, upon which M. Faure had applied this coating in order to arrive at, 1, a quicker result by doing away with the need of the process of "formation"; 2, a greater capacity

in the same space, by means of the larger bulk of the oxide ready for immediate action. It was at once declared, by those interested in the new cell, that weight for weight it had 40 times the capacity of the Planté, but experiment by others reduced this to a very small superiority, in fact to one and a quarter times the capacity. Then followed a host of "inventions," some of which were associated in due course with the first, all directed to the objects of, 1, securing the contact and adhesion to the lead plates of the spongy mass of oxide; 2, obtaining the spongy mass from different materials; and 3, of developing the original Planté system and enlarging the surface of the lead in a given space. A few have attempted other substances, but so far experience confirms the result of M. Planté's own experience, that nothing is practically so good as the two lead surfaces in acid. Even the latest, that of Mr. Brush, is the same; a good deal of expectation has been excited about this by means of the usual rumours; but the lengthy specification, with its 56 claims, does not appear to add any practical information to what was already well known.

270. FORMATION.—In all forms of the lead secondary battery, the essential point is the presence at the one plate of a supply of peroxide of lead, in *quantity* adequate to the work, in *condition* to do it effectively; the difficulty is to unite these two. When a current is first passed between two sheets of lead in sulphuric acid from a source capable of freely decomposing water, that is with an E M F exceeding 2 volts, a thin film of brown peroxide of lead forms on the surface of the anode; then oxygen escapes and no more peroxide forms: the reason is that the peroxide being a conductor of electricity, the action occurs at its surface in contact with the liquid, and this surface can undergo no change by the oxygen generated there. Only a very small charge can be stored or given up as a current. If at this stage the current is reversed, first the peroxide is reduced to lead which is in a more porous state than at first, and a thin coat similar to the first is produced on the other plate. A fresh reversal allows a larger quantity of peroxide to be produced on the first plate because its granular state presents a larger surface and holds acid within its pores. After a few such reversals the limit of this increase is reached, and then it becomes necessary to allow a period of rest after charge. Now, *local action* occurs between the surfaces of lead and lead peroxide in contact in presence of acid: precisely the same conditions exist there as enable the two separate plates to generate a current.

271. This action, the source of the E M F of the secondary

battery, is the tendency of the second atom of oxygen in PbO_2 (which atom has in fact been forced into the molecule) to pass over to the lead surface, and there produce the more normal protoxide PbO, thus rendering both surfaces alike: other actions follow, but this transfer of the atom of oxygen from the peroxide to the lead is the essential action. But this occurs in the presence of sulphuric acid, which unites with the newly formed protoxide of lead, producing sulphate of lead, in a white film insoluble in the acid. We have in fact first $Pb + PbO_2$ becoming $PbO + PbO$, and then $PbO + H_2SO_4$ becoming $PbSO_4 + H_2O$.

The same effect is produced by local action on the surface of the peroxidised plate, which then becomes a plate of lead coated with sulphate of lead, and this again covered with peroxide.

272. *Reduction of lead sulphate.*—On now reversing the current, the spongy films of peroxide and sulphate of lead are penetrated with acid, which therefore is in contact with the lead surface, and when decomposed, presents its hydrogen to the sulphate of lead which is reduced to lead in a spongy condition. It is strange that such distinguished chemists as Messrs. Gladstone and Tribe should have said, "It may seem at first sight improbable that an almost insoluble salt of the character of lead sulphate should be decomposed under those circumstances," and that Dr. Lodge should have stated that it is not readily reduced. This reaction is of course the basis of the action of the sulphate of lead battery, § 236, well known for many years. Messrs. G. and T. show, however, that when two plates coated with $PbSO_4$ have current passed between them, not only is the lead sulphate on the cathode or – plate reduced by hydrogen to grey spongy lead, $PbSO_4 + H_2 = Pb + H_2SO_4$, but that the oxygen converts that on the anode to peroxide, $PbSO_4 + O + H_2O = PbO_2 + H_2SO_4$, regenerating the acid at the same time.

A series of such reversals therefore converts the surfaces of the lead plates into a mass of spongy lead capable of ready conversion into peroxide of lead. But this mass of spongy lead, and also the peroxide coating its surfaces, is in actual molecular contact with the lead plate itself; it is not merely in mechanical contact with the lead plate, but an actual part of the plate. It is in this fact that the principal advantage of the simple Planté consists.

273. *Time of formation.*—The directions of Planté are to effect six or eight reversals of current the first day, prolonging the successive charges: this is to be continued the next day till the

duration of useful charging becomes a couple of hours: at this limit it becomes necessary to give intervals of rest between the charges, during which the local action described § 271 takes place: these rests require gradual prolongation to several days and even weeks; after the cell approaches the capacity of storage intended, the current should not be reversed, but the cell should simply be charged and discharged as if in actual work. The process of this forming, therefore, occupies some months except with very thin plates, and if pushed too far, the whole substance of the plate may be converted into peroxide, which would render it liable to break up and would increase its resistance.

274. *Heat* assists the formation and reduces the time required for the process: therefore during the process of charging the temperature may be advantageously raised to from 100° to 160° Fahr., and allowed to cool as soon as the charge is effected. But heat is objectionable in actual working, because it facilitates the oxygen and hydrogen assuming the gaseous state and going off to waste.

275. *Alcohol* added to the extent of 5 per cent. to the acid solution is said to assist the formation. Mr. E. Berliner states: (*Electrician*, ix. p. 39) that it "requires but an hour to develop a heavy oxide surface capable of taking a large charge."

276. *Nitric acid* is recommended by Planté, who says that by soaking the plates for some hours in nitric acid mixed with equal volume of water, he has greatly reduced the time of formation. The effect is to produce a porous surface more quickly acted upon: but it is evident that for this treatment the plates should be thicker.

277. *Electro-deposited lead* has been tried by many for the same object: but lead is a very troublesome metal to deposit; unlike other metals it does not spread as an even film, but will dart out in fine arrows from points on the surface, which either fall off, as they lengthen, or close the circuit to the other plate—for this reason the presence of lead salts in solution, or the use of acids, &c., which will dissolve lead, is very objectionable.

278. *Amalgamation of the lead* has been employed and is patented by Paget Higgs, who claims its first use. It is by no means clear that it is an advantage on the whole: it must tend to weaken the lead, and therefore lead to fracture of the plates. It is not desirable or useful at the peroxide plate because it resists the formation of PbO_2 and tends to form oxide or salts of mercury: the mercury also prevents the molecular union of the lead and peroxide, which therefore tends to separate from the

plate. It is probable that mercury facilitates the absorption of hydrogen at the lead plate, but even there the advantage is very doubtful, because, in regular working, the real action which goes on is the reduction of the lead sulphate which has been formed during discharge.

279. CONSTRUCTION.—The plates may be either flat plates interleaved like those of a condenser, or they may be large plates rolled up as cylinders, or folded up together.

Flat plates give a simpler construction and have the great advantage that they can be "formed" in a separate vessel and combined as desired; each can also be removed singly in case of injury and easily replaced. They have a serious disadvantage, however. It is evident that the molecular volume of lead salts exceeds that of lead, so that there is a constant expansion and contraction going on, which tends to produce bulging surfaces, and this much more readily upon flat parallel plates. It is therefore desirable to introduce slips of glass or other insulating material to resist this and prevent the plates coming in contact.

The cylindrical form is made by laying a long sheet of lead on a table, placing upon it a number of strips of soft vulcanized rubber arranged diagonally upon the lead, then another sheet of lead with similar diagonal strips: the sheets are then rolled up firmly so as to form two parallel spirals separated from each other. The insulating strips can be inserted as the rolling up proceeds.

The thickness of the lead must be sufficient to bear its own weight and the strains put upon it after use: the peroxide plate should therefore be about double as thick as the other: in large batteries lead 1 millimetre thick is used, which is ·03937 inch, or about 24 sheets to the inch. One square foot of lead 1 inch thick weighs 59·1 lbs., therefore this would be about 2½ lbs. lead. The smaller cells are made of lead little thicker than that prepared for damp walls, which is about 4 to 5 ounces per foot. For ordinary purposes it is probable that sheets of 1½ lb. and 1 lb. would be most advantageous, with the formation carried so far as to convert ½ lb. of the lead to peroxide on the one plate.

280. *Connections* must be provided to the sheets in either form, and the best is made by strips of lead attached carefully to the sheets by soldering which should be well protected by good cement: copper wire should not be used, as it is sure to be acted upon, and form salts which will exert a very mischievous action.

281. *Containing vessels* may be of any suitable material, but glass has the great advantage of permitting the action to be

watched: if lead vessels, or wood lined with cement or other opaque vessels are used, they should be covered with sheet glass for this reason. They must not be entirely closed, because gases are generated and must be allowed to escape; they should not be uncovered, in order to resist evaporation and also for prevention of dirt which would be likely to result in short circuiting the plates, a thing very likely to occur and obviously injurious to the working, § 298.

282. *Space for acid* must be allowed, sufficient to effect the action, therefore the distance of the plates must be so adjusted: circulation cannot be depended on, but it is desirable to raise the bottom of the plates above that of the vessel, and to allow the liquid to rise above them, in order that the heat and escape of gas may tend to produce a current, and to draw the external acid between the plates. One pound of lead requires ½ lb. of acid to convert it into sulphate, and as by the foregoing proportions there would be ½ lb. of lead to be converted on the two faces of lead opposing per square foot, this requires space for ¼ lb. of acid, which diluted as 1 to 10 would be contained in a space of ⅛ of an inch between the plates.

283. *The strength of the acid* varies during the action, becoming strongest when the charge is complete and one plate is converted into spongy lead and the other into peroxide: when discharge is completed a great part of the acid is absorbed in the formation of sulphate of lead. Several consequences result: 1, the resistance of the battery is lowest just when its E M F is highest and *vice versâ*, which introduces a variation in the current generated at different periods of discharge; 2, where the material consists of a porous mass containing liquid confined among its interstices, the acid may be entirely removed at an early period of the discharge and consequently much material remains unacted on; also, the residuary liquid being highly resistant at the next act of charge, the current cannot reach the material. As a consequence a cell containing a large mass of active material may be able to do but little work: this defect is also an accumulative one; portions of the mass become practically non-conducting and insulate other portions to which the acid has access, because in very dilute acid, instead of the normal sulphate $PbSO_4$, there is a tendency to produce the basic sulphate $PbSO_4+PbO$, which is not readily reduced by hydrogen. It is owing to actions of this kind that the plain Planté with its thin film of active agents, presenting a large surface freely bathed by circulating liquid, works better in the long run than the improved forms which concentrate a large mass of active material in a small space.

Dr. Frankland finds that the changes of strength of acid can be utilized to indicate the state of the cell, by means of an hydrometer floating in the liquid. It is obvious that no law can be laid down, as the changes would depend upon the quantity of acid in a given cell, but he found in his own cell that a change of ·005 in the specific gravity meant storage equal to a current of 20 ampères for an hour. Such a test will obviously be useful only where the acid is capable of free circulation.

284. *Charging.*—In order to charge a secondary battery it is necessary to employ an E M F greater than its own, and greater in proportion to the rate of charge desired. All such excess of E M F. is energy lost in overcoming resistance, therefore slow charge is most economical under this head, though other practical considerations have to be taken into account; that is, against energy lost at the rate of the square of the current C^2 generated, we have to consider time, and interest on plant. But in addition to the loss of energy involved, a small charging current is desirable for two good reasons, 1, the product is in better condition, the particles in closer contact and better electrical connection: 2, there is less loss by uncombined gases escaping.

285. *Loss of gases.*—Throughout the charging there is a constant escape of gases going on, chiefly oxygen. But the loss of either gas means total loss of the equivalent of electricity involved in the decomposition from which it arises. If O is obviously wasted, it is certain the H is lost too, or on the other hand, that the total power of the cell is reduced by its incapacity to take up the O. But the escape of H indicates at once either that the rate of charging current is too great, or else that the limit of the economical charge is approached. As in all cases of electrolysis we are brought to the question of *density of current*, the rate at which a unit area of surface can act properly, and this in the case of a secondary receiving charge, is of necessity a *lowering capacity*, because it is not mere surface we have to consider, as in the case of the zinc of a battery which remains unchanged, but the diminishing quantity of sulphate of lead upon that surface remaining unconverted. But as shown § 283, the increase of free acid tends to increase the current, and the combination of these two causes results in a growing loss of gases as the charge proceeds. Obviously, therefore, it is bad economy to press the charge to the full capacity.

Messrs. Gladstone and Tribe give an experiment on this point which, though actually relating to two plates covered with red lead, is a fair representation of what occurs in general cells. They passed a current of 1 ampère for thirty-one hours through the two plates, of which, however, they do not give the area.

Time, Hours.	Hydrogen,		Oxygen,	
	lost.	absorbed.	lost.	absorbed.
1	0	312	0	156
10	21	297	99	60
20	270	50	111	49
31	300	6	135	18
Total ..	5230	4489	3120	1737
Total Capacity ..	4574	..	1294	

The figures represent cubic centimètres, and as the oxygen stored exceeds the capacity of the materials it is evident that either the plate itself received some or else a large quantity remained "occluded." But the figures for each hour's action show distinctly the lowering capacity, and the unwisdom of pushing the process too far, or too fast.

286. *Occluded gases.*—It is generally thought that hydrogen is retained by the spongy lead, § 258, as it is by palladium, but recent tests render this doubtful. Oxygen, however, is certainly retained to a considerable extent, as is shown in § 285, and also by its actual escape from the plate while at rest after charge. A little hydrogen also is certainly retained, as we know that metallic surfaces always retain with great tenacity a film of any gas to which they have been exposed. The higher initial E M F has been attributed to these gases, § 287. It is probable that the oxygen is in the form of ozone or peroxide of hydrogen rather than of ordinary oxygen, and the formation of these substances may be expected from the high degree of E M F under which the decomposition occurs to enable peroxide of lead to be formed.

287. *The electromotive force* is about volts 2·25 immediately after charging, but falls spontaneously to volts 2. This high initial force cannot be due to the free H and O, because their form of combination is only 1·5, but it is easily accounted for by the presence of ozone, which is oxygen charged with a higher energy in order to force the third atom of O into the molecule. The normal E M F of 2 volts is subject, in working, to a fall such as occurs in ordinary batteries to an extent increasing with

the rate of current, and due probably to the change in the liquid particles adjoining the plates; therefore the E M F rises again after a short rest has allowed fresh liquid surfaces to reach the plates by diffusion. The average rate of working E M F is probably 1·9 to 2 volts.

288. FAURE'S BATTERY.—This, which is the wonderful box of electricity mentioned §§ 268, 269, is the Planté cell in which the process of formation is nearly done away with by coating the plates with a paste of red lead, which is converted by the electrolytic gases into spongy lead and peroxide of lead. All the remarks made as to lead batteries, therefore, apply to this as to the simple Planté. The only question is whether this use of the red lead or any of the other substitutes proposed, such as litharge, sulphate of lead, reduced spongy lead, &c., is an advantage. It saves the formation, it concentrates the material into smaller bulk, and it is claimed that an equal weight of material does more work. On the other hand, it has the disadvantages arising from conditions described §283. The mass of material is only in uncertain mechanical contact with the conducting plate instead of in molecular union, and therefore subject to disintegration. This defect applies to the multifarious "inventions" based on the "lead tree," in which every imaginable mixture of materials has been patented for obtaining a spongy mass of lead having larger surface in small space, and to collections of shot, granulated lead, carbon, &c.

289. At first, this cell was made, of necessity, with some material such as felt, asbestos cloth, &c., to bind the material to the plates. These all add to the resistance, resist circulation of liquid, and sooner or later rot away and disintegrate. By the combination of the patents of Swan, Sellon, and Volkmar with that of Faure, this battery assumes the form of small masses of the porous material contained in spaces in lead plates. There are a variety of means of effecting this, such as making the plates of an open network, or of perforated sheet; but the whole question resolves itself into the thickness of the porous mass which can be used to advantage; and its proportion to, and effectual securing to the lead conductor.

290. *Dimensions and capacity.*—The latest improved form is made in several types. A. consists of 7 positive plates, each 37 × 23·5 cm. square, and 3 mm. thick, perforated with holes 6 mm. in diameter, every 10 mm. apart: these are interleaved with 7 negative plates of same size only 0·55 mm. thick, perforated like the others; the 7 positive plates weigh 16·66 kilos., the 7 negative 2·77. The red lead spread on their surfaces

weighs 22·13 kilos. The box is of pitched wood 45 × 20 × 40 cm., weighing 10 kilos. with its cover. The charged cell weighs 63 kilos., and is said to contain 375 ampère hours of current with an E M F of 2 volts. Other smaller types contain 225, 150, and 75 ampère hours; the last with a weight of 8 kilos.

291. *De Meritens'* cell was the first modification of the Planté. The plates are formed of thin sheets of lead placed one over the other like the leaves of a book, and cut off in slices, and the ends soldered together to unite them. The result is a block of lead about one-third of an inch in thickness penetrated with a vast number of slits in which the action is carried on, and which become filled with peroxide of lead in the one block, and spongy lead in the other. This gives much concentration of material, but the formation has to be effected as in the Planté, while it is evident that the action is limited by the amount of liquid which penetrates between the films of lead.

292. *Kaboth's* cell is a modification of the Meritens; it consists of similar plates built up of thin sheet lead, but these strips are passed through a pair of rollers which produce diagonal corrugations. These being interleaved with plain strips, the plate is composed not of surfaces in close contact, but of a series of small tubes sloping upwards and tending to produce a circulation of the acid throughout the plate; this appears more promising than the plain strips, but in all likelihood the tubes would soon be filled up. A later improvement, by M. Pezzer, replaces the plain strips, by doubling the corrugated strips back upon themselves so as to form a sort of fringe. The plates are separated by a porous cell which of course adds to the internal resistance while protecting the plates against accidental contacts. It would appear that the double corrugation is a disadvantage, because it must resist the formation of currents between the plates, by the ribs crossing each other.

293. *Messrs. Fitzgerald, Crompton*, and others have united in producing a battery plate composed of a thin sheet of lead upon which is built up a coating of spongy lead derived from the reduction of chloride or other salts of lead submitted to a certain amount of pressure by which the particles of lead are to some extent welded together, and made coherent. This results in a plate of large capacity and of very rapid "formation," but whether it overcomes the difficulties of § 283 will have to be learnt in actual use.

It has been found that these cells are very greatly improved by using, as the hydrogen receiving plate, an electrode composed of a mixture of granulated carbon and red lead. Such mixtures have been employed by others also, but have failed because used to receive the oxygen: carbon as the electrode for this purpose fails, because the oxygen being in a peculiarly active condition, as ozone, &c., acts upon the most refractory carbon: this is not the case with hydrogen, and the result is that when used for this one plate, carbon succeeds; but when used at both plates or to receive oxygen it fails.

294. *Sutton's battery.*—It is needless to mention the many other patentees who have made slight modifications of the lead secondary battery. But Sutton's is of a different order, as it consists of two metals and a metallic salt. It is composed of a lead plate to be peroxidized, and a copper plate to be alternately dissolved and deposited from the solution of sulphate of copper. It will serve well for amateur purposes and small currents, though its E M F is lower than that of lead. I have also employed a similar cell with amalgamated zinc and zinc sulphate. But such combinations fail on any large scale for the reasons to follow.

295. *Metallic solutions*, while promising in appearance, do not answer in practice for the same reason that I have had such frequent reason to refer to. The action, unless very slow, alters the layer of liquid in contact with the metal, which then refuses to act: in charging, after the first action there is no metallic salt present to decompose, but only acid which gives off gas, and so the metal deposit becomes non-coherent: in discharge the metal salt forms too rapidly to dissolve, and crystallizes on the plate.

296. *Acid solutions* other than sulphuric might be used and no doubt will; but hydrochloric acid when electrolysed does not give up H and Cl simply, it is always accompanied with oxygen, and the result is the formation not of chlorides, but of oxychlorides, which are exceedingly refractory in reduction; for this reason the chloride of silver battery fails in reversal, or else it would constitute an admirable storage battery. Then the chloride of lead is partly soluble and will not answer for reasons given § 277, which also limit the use of many other acids and salts.

297. *Alkaline solutions* cannot be used with lead because they dissolve it, but they may be employed with some other metals, as iron, which at one plate would absorb H and form peroxide at the other, forming a battery of rather low E M F.

298. GENERAL MANAGEMENT.—In charging a number of cells it is necessary so to arrange them in series and in arc as to distribute them on the same principles as ordinary battery cells when a number are used together.

So many must be ranged in series that the number multiplied by the E M F is so much below the charging E M F as allows the required rate of current to pass; that is to say, E (or 2·25) × *n* × 1·25 = E M F of source, assuming that this is to exceed the counter-force of the battery by one quarter.

So many must be ranged in multiple arc as brings the united resistance to such a ratio to the available E M F as will permit the intended rate of current to pass; such rate being well below the proper working *density* suited to the area of the plates.

It is of the utmost importance that all cells to be worked together shall be fairly equal, for as in a chain the capacity of a combination is that of the weakest link: if some cells become inactive in discharge, they are not merely useless, they begin to take charge in the opposite direction and oppose their E M F. If several sets in multiple arc differ in E M F, which will occur if their conditions differ, some of the sets will not get charged, or if left so connected when the source is not acting, they will be reversed and the charge wasted.

The *charge* should not be carried to more than three-fourths of the capacity. The *discharge* should not be carried further than three-fourths of the charge actually stored; and the battery should not be charged, if avoidable, long before it is intended to be used.

Each cell should be occasionally tested as to its condition, in order to discover any derangement, or accidental short circuit, and any cell showing unusual evolution of gas should receive immediate attention.

N.B. Galvanometers should always be kept in circuit to give warning as to what is going on, and automatic cut-outs are very useful in case of a failure of the source or other accident. Such appliances are easily made with an electro-magnet inserted in the circuit or in a shunt circuit, with a permanent steel magnet for the armature mounted on a spring and completing the circuit only when held down: the attraction of the armature for the core will hold it down ordinarily, but if a reverse current arises the armature leaves the magnet, breaks the circuit, and can be made to ring a bell to call attention.

299. WORK DONE BY SECONDARY.—It is asserted by some that these batteries will return 90 per cent. of the energy stored; but words can be used to delude, and probably if pushed to explanation we should find *electricity* substituted for *energy*. It is quite likely that 90 per cent. of the electricity, reckoned in coulombs, might be obtained, provided the battery were used not long after charge.

Quantity of electricity is in fact current multiplied by time, $C \times t = Q$, and if we formulate

$$\frac{\text{Quantity of charge}}{\text{Quantity of discharge}} = \text{ratio of useful work,}$$

we have of course the waste by *local actions*, which is always inevitable in electrical operations.

But for these large currents the coulomb is too small a unit, and it is becoming common to reckon by "ampère hours," that is to say by the quantity represented by an ampère current sustained for 1 hour or 3600 seconds, so that "ampère hour" means 3600 coulombs. See § 386.

But this is a small part of the loss. What we are really concerned in is the *energy*, and this is related to $C \times E$ and may be measured in "volt-ampère hours." It depends upon the E M F as well as the current, and as the E M F of charge *must* exceed that of discharge, and *may* probably exceed it by one-third, we have here an inevitable loss, which cannot be defined for all cases, because it will depend upon the ratio of the external and internal resistances.

This only gives us the loss upon actual storage, but we must add that lost in the act of charge, the energy carried away in the escaping gases, § 285. And when all these are considered it is almost certain that, on the average, the use of storage batteries means the loss of 50 per cent. of the energy, as compared with direct working. This means doubling the cost, irrespective of the value and expense of the battery itself: it is as though only one-half of the gas put into a gas-holder could be delivered from it, and this is why secondary batteries have come into little use, notwithstanding all that was hoped from them.

CHAPTER V.

MEASUREMENT.

300. The great distinction between modern and ancient modes of investigation is that modern science is based upon exact, minute measurement, so that causes and effects are truly balanced and actions traced from point to point; then when different branches of phenomena have been traced to their connection, an explanation, a *theory* can be arrived at: the science "falsely so-called" of the ancients was vague, the theory or conception was first set up *a priori* from a general view of phenomena, and then the facts were fitted to it as well as they could.

Electrical measurements relate to the three divisions, §§ 168-70, electromotive force, resistance, and current, and the general theory will be explained further on, but it is better to commence with the facts the theory is based upon, and the instruments in use, following, in fact, the process by which the existing system has been developed, and commencing with the actual phenomena of current.

301. MEASUREMENT OF CURRENT.—This may be effected by three actions of the electric current, § 147, viz. by the *magnetic*, the *chemical*, and the *heating* effects, which are examined by instruments called *Galvanometers*, *Voltameters*, and *Calorimeters*. Each has its use. The galvanometer interferes very little with the actual passage or work of the current, and indicates, by the motion of a magnetic needle, the actual current passing at each instant, and therefore any variations occurring. The voltameter measures the total quantity of electricity which has passed in a given period, or which is developed during a given action; and the calorimeter testifies to the relations of energy to the electrical work done.

302. GALVANOMETERS.—When a magnetic needle and a galvanic conductor are placed parallel with each other, they tend to place themselves at right angles to each other; the action is reciprocal, either the magnet or conductor will move, but the motion of the needle is obviously the most convenient for use. If *over* a magnetic needle at rest, and in the same direction, we

place a wire, and through it pass a current entering at the southern end, the needle turns with the N. end to the left, or westerly; if the wire be *below*, the needle turns to the right. If the direction of the current is reversed, that is, if it enters at the N. end, the actions are reversed. If the wire makes a turn round the length of the needle, it is evident all these conditions come into play at once, for the current entering at S. and passing *above* the needle, when the wire turns to the lower side, the current passes from the N., hence both the actions are the same and the needle is deflected to the left with double force; each turn has a similar action, varying, however, in its amount with its distance from and position as regards the needle, on principles which will be explained hereafter.

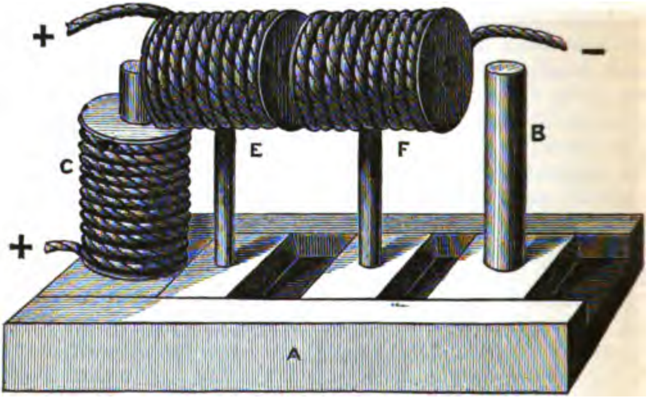
303. GALVANOMETER NEEDLES.—These are frequently made too heavy: the heavier they are the greater is their "moment of inertia" and the force required to move them, and the longer they are in coming to rest. The best material is a watch or clock spring softened, in order to shape and arrange it, then hardened by heating to a low red heat and plunging in water.

Long needles have most directive force and give more decided indications, but take longer in coming to rest; they are therefore best adapted to vertical galvanometers. Short needles are less affected by external magnetic disturbances and come quicker to rest; their deflections are also more equal in value at different parts of the scale.

304. *Magnetizing* may be effected by placing or rubbing on the poles of a permanent magnet. Fig. 49 is an apparatus which will be found very convenient for obtaining highly saturated needles.

It consists of an iron base A forming a sliding groove to hold the other parts in position. C is an electro-magnet which may be fixed to the base; B is the core of the other arm which can be adjusted to the length of the needle, the ends of which rest on the top of C B. E and F are coils connected together by a flexible wire at the middle, and supported on feet fitted to the groove in A, so that the needle can be inserted within the coils. The wires are so connected that the current divides between C B and E F, but the circuit of E F is to be provided with an interrupter, or one wire can be attached to a rough file and the other run along the file, so as to keep up a strong magnetism in C D, to which the needle acts as armature, while a strong intermittent current passes around the needle in E F. A simpler but less effective apparatus can be made with the coils E F alone, if they are fitted with sliding rods and tubes to keep them in position. If the coils are made of No. 20 or 22 wire, a single bichromate cell will do the work effectively. The coils should be marked to show which end gives N. polarity when connected to + of the battery: astatic pairs are of course inserted separately in opposite directions.

Fig. 49.



305. *Suspension.*—For delicate instruments, the only satisfactory suspension is by a silk fibre, or such a thread of silk as may be drawn from a ribbon; hairs are sometimes used, but they offer a strong resistance to motion. The fibre should be attached at its upper end to a sliding rod (in good instruments a compound screw is used), which lifts without twisting the fibre. For ordinary instruments with a single needle, an agate centre fixed above the needle is used. Double needles may be suspended in a similar manner; the agate centre is first fixed in a thin brass tube by turning the edges lightly over it, the upper needle is then attached to it, if double by placing one part on each side, if single either by a hole opened in the middle or by doubling over the top and bringing down on each side so as to grip the tube firmly, and then touching lightly with solder, or an indicator may be similarly fixed. The lower needle may be made of two pieces of watch-spring, one fixed on each side of a very thin light tube, the ends of the needles drawn together and soldered or riveted. The tube should be under $\frac{1}{4}$ inch in bore and fit firmly upon or in the upper tube carrying the agate, and when the two needles are exactly adjusted a touch of solder will fix the tubes together, or, if preferred, the junction may be made by screwing. To adjust

the needles, a suspension point is placed upon a movable board having a line marked upon it; one needle being magnetized, the line on the board can be placed true N. or S., and the other needle or indicator being added, the tubes are moved slightly till the united system is correct.

306. *The swings of the needle* correspond to those of a pendulum, and for the same needle always occupy the same time, whether the swing be across the whole arc or over only a degree or two: this gives a means of adjusting astatic needles to the desired delicacy and also of controlling the movements of needles. If there is a commutator or break in the circuit it is easy to make and break circuit so as to lead the needle slowly up to the proper deflection with scarcely a return swing, or to meet the swings, and bring it to a dead stop, which saves much time in observations: but the number of vibrations of a needle may be diminished or arrested by *damping* in various ways.

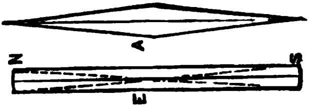
(1) A plate of copper close to the needle, either as the dial plate or as the internal frame of the coils, checks the swings by the induced electric currents set up in the copper.

(2) A vane of paper or mica may be attached either to the needle or indicator.

(3) A similar vane may be attached to the bottom of the wire which connects the needle to its fibre, to work in a chamber under the coils; sometimes this chamber contains mercury or some liquid, such as glycerine and water, the effect of which is to cause the needle to move slowly up to its point of rest without swinging; or the chamber within the coils may be so used.

307. *Needles should be formed* with points tapering to near the middle: the ends should not be square, because the current acts on the magnetism, and would tend to pull the poles over to the corners as shown Fig. 50, and to disturb the relation between the needle and the indicator (see § 134). When formed of thin plates on edge this cannot occur, and the shape is of no consequence. In some tangent galvanometers compound circular needles are used, consisting of a disc of mica on which parallel strips of steel such as pieces of sewing needles or watch-springs are cemented, long in the middle and shorter at the sides: it is considered that these suffer less displacement in the magnetic field of the current than straight needles do.

FIG. 50.



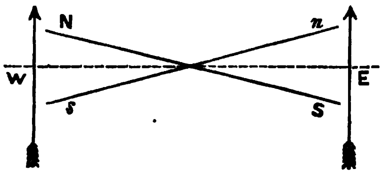
308. *Indicators* may be made of a thin, hard drawn wire,

aluminium alloyed with a little silver being best, or of a thread of black glass, which may be drawn out over a Bunsen's burner or spirit-lamp, by heating a small rod or tube (such as a bugle) to fusion, and drawing the two ends rapidly but steadily away. A more correct indicator, having no weight, is obtained by attaching to the suspending wire a mirror made of a circle of microscope glass silvered, upon which a ray of light is allowed to fall from a shaded lamp placed upon the continuation of the zero line of the instrument. The mirror is attached to the wire, or in Thomson's reflecting galvanometer, to one of the needles, by shellac varnish, or by a cement such as coaguline.

309. Astatic Needles are a pair of needles fixed upon a wire or a tube, as above described, with their poles in opposite directions, so as to neutralize each other: if perfectly adjusted they would have no tendency to assume any particular position.

It is often stated in text-books that such needles place themselves E. and W., and an elaborate mathematical explanation is given. Fig. 51 explains the cause simply. N S, *n s*, are two oppositely arranged needles, which are not arranged exactly in the same vertical plane (this being of course exaggerated in the figure): it is evident that the result is to form two virtual magnets or fields at the opposite ends, both having the same direction, as shown by the arrows; these virtual magnets place themselves in the usual N. S. position, and as a consequence, the visible system, which is a neutral one and serves simply as an indicator, places itself E. and W. This occurs only when the needles are exactly equal. In practice it is necessary to make one of the needles so much more powerful than the other as to bring the system to rest upon the zero line: the upper needle if made longer does this by its greater "moment."

Fig. 51.



310. *Magnetism of needles.*—The actual strength of the needle's magnetism has no effect upon the deflection, except indirectly by the relative effect of the resistances of the support; two exactly similar needles will be alike deflected, though one be strongly and the other weakly magnetized. The reason is that the needle is affected by two forces, the effort of the current and the earth's magnetic field, and these are equally reacted on by the needle itself. This applies only

to single horizontal needles. A compound pair will deflect differently when strongly and weakly magnetized. A needle vertically suspended, will also deflect further if strong than if weak. Different needles, if different in length, will also be differently deflected by the same instrument and current.

311. *Resistance to motion.*—The actual measuring power is due to the resistance offered to the action of the current. In the ordinary single-needle instruments, this resistance is caused by the earth's magnetism; the result is due to the relative strength of the two magnetic fields, earth and current, acting at right angles to each other: in this form, therefore, the same current will produce different deflections at different parts of the earth; of course, also, the neighbourhood of magnets or currents, or of masses of iron, will disturb the action: in some cases this is remedied by using permanent magnets to control the needle, in place of the earth's magnetism, of such power as to render other agencies of small effect. In other forms a mechanical resistance is employed, such as the torsion of a wire or fibre, or a bifilar suspension. In vertical galvanometers the resistance is the extra weight of the lower parts of the system.

312. STAND FOR GALVANOMETERS.—There is often some trouble in arranging instruments so that the needle stands directly upon the N. and S. or zero line, and many good galvanometers are made movable on an axis for this purpose. A revolving stand is, however, a great convenience for a variety of purposes. The base should be of well-seasoned wood, and fitted with three levelling screws, and with a truly vertical axis rising from its centre. Upon this revolves a somewhat smaller disc, which may advantageously be carried by small wheels between the two boards. At opposite ends of one diameter there should be set-screws or springs to hold the disc steady when adjusted. By marking the edge of one of the discs in degrees of a circle and attaching a pointer or vernier to the other, this stand converts any form of galvanometer into a sine galvanometer.

313. GENERAL PRINCIPLES.—When a magnet is suspended simply in the magnetic field of the earth, it stands magnetic North and South, which is called the zero line.

When the magnetic field of the earth is obliterated in the neighbourhood of the needle, as by means of external magnets, or its influence is put an end to, as in a perfectly astatic needle, the magnet has no directive influence whatever, and then, under the influence of any electric current, it places itself in the axis of the field due to this current; that is, if the wire be placed in the magnetic zero line, the needle places itself at right angles, or at 90° of deflection.

When an ordinary single needle is placed at the centre of a current moving in the plane of the magnetic meridian, this needle is deflected to a certain degree dependent upon the strength of the current. In this position it is influenced by *two equal and opposite forces*, the valuation of either one of which, therefore, values the other.

Of these two forces one is known—that is to say, the action of the earth's magnetic field upon the needle, and, if we can express this force in some definite system, we have equally the measure of the galvanic current, which, in the given circumstances, exactly balances it.

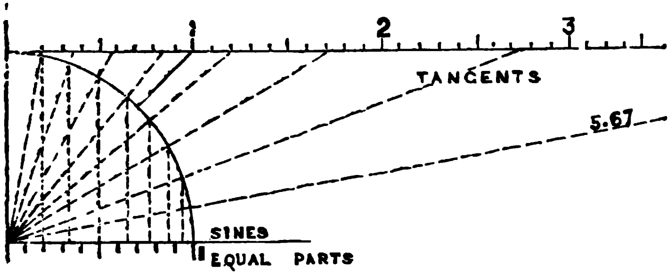
The effect of the number of turns of wire and their position is explained § 327. This is frequently explained in text-books by a vast array of formulæ; but unfortunately, as with many other highly wrought mathematical formulæ, they too often tend to hide away out of sight the real principle which gives them existence.

The student should clearly realize that all the theories and laws set forth as to the influence of distance of the wire from the needle resolve themselves simply into this one point, the development of the magnetic field due to the currents in the wires.

The influences of the two forces are, according to known laws, proportional to the sines of their relative angles, that is to say, considering the one angle of deflection alone, the pull of the earth's field upon the needle is proportional to the sine of the angle of deflection, while the pull of the current is equal to the cosine of the same angle. To value these trigonometrical expressions, however, we must attach some definite measurement to them, because the unit pulls of the two forces are not the same. This object is attained by different writers by various formulæ, of which I will quote one from De la Rive, vol. i. p. 338, as being about the simplest:—"Now, by supposing that the angle of deviation described by the needle under the action of a current is i, the force which tends to bring it back into the magnetic meridian, and which produces equilibrium to the deviating action of the current, would be f sine i, f being the force of the terrestrial magnetism for the angle whose sine is 1, viz. for the angle of 90°. On the other hand, if F represents the action of the current upon the needle when the latter is placed parallel to the current, this force will become F cosine i when the needle makes an angle i with the direction of the current; for F cosine i is the component of F acting under the angle i. F cosine i, therefore, is the expression of the deviating force of the current upon the needle, when the angle of deviation is i; it is, consequently, equal to f sine i, since it makes equilibrium with it. From F cosine $i = f$ sine i we deduce $F = f\frac{\text{sine } i}{\text{cosine } i} = \text{tang } i$. But f is a constant quantity, at least in the place where the observation is made, because it is the directive force of the earth. Therefore F, or the force of the current, is proportional to the tangent of i, or of the angle of deviation."

314. I prefer to make principles evident to the eye, and offer the following explanation. Instead of considering the two forces as *pulls* at right angles, which necessitates the consideration of the sine and the cosine of the angle of deviation, two measures which, except at 45°, are *unequal*, while the forces they measure are *equal*, let us, remembering that the earth's magnetism and the current are acting from the same plane, treat one as a *pull* and the other as a *push* of equal power in the opposite directions; *we now measure them both at once*, they are both equal to the sine of the angle of deviation. Let us now commit a mathematical heresy, and declare that the sine of an angle and the tangent of an angle are the same thing, but in doing so let me ask any critic who may notice this assertion *not to quote it without its explanation*.

Fig. 52.



315. Fig. 52 will assist readers unfamiliar with trigonometry to comprehend terms often met with. The vertical line forms the perpendicular of a right-angled triangle, of which the base or other side of the right angle is the divided line of tangents: the angle measured is that formed at the lower part, where the radial lines meet; these lines forming the third side, or hypothenuse of the triangle. The dimensions of the *angle* relate only to the opening of the two lines, that is to say, to the arc of

circle which they inclose, but may be measured by any other of the essential lines, provided a unit or known length is taken for one of these lines, which then governs the size of the right-angled triangle formed. The proper unit is called the *radius*, as from that the circle is struck: radius then is 1; in the figure one inch. The radial dotted lines inclose areas of 10° each from the perpendicular radius, and lines drawn from the end of the radius to where the lines cut the circle are the chords of the arc. The horizontal line is that of *tangents*, defined for each angle by the prolongation of the secondary radius inclosing it; the unit tangent, that equal to the radius, or 1, is the tangent of 45° (shown by a line from 1 on the scale to the arc). The *sine* of an angle is a line drawn from the intersection of the secant to the radius, parallel with the tangent line; its unit length, equal to radius, 1, is the sine of 90°, and the lower divided line is that sine divided to correspond with the actual sines, not shown themselves, but defined by the vertical dotted lines, which are the *cosines*, or sines of the complementary angle. The radial dotted lines extending to the tangent line show the *secant*, which has no unit, 1, as its unit is radius itself, which mathematically may be called the secant of angle 0°. It will be seen that the sine and tangent are parallel lines both defined by the same secant, the sine inside and the tangent outside the circle, and in fact that by taking the cosine for a fresh radius, the original sine becomes the tangent: this is expressed in another way in the formula commonly used (as by De la Rive above) that sine ÷ cosine = tangent: this is the usual explanation of the fact that the two balanced forces under consideration, one represented by the sine and the other by the cosine, are truly measured by the tangent. The advantage of the tangent scale is that it is one of *equal parts*. Scales of natural, i.e. proportional, sines and tangents are to be found in most engineering pocket-books; and logarithmic values, which are necessary for many calculations, are furnished with the common logarithmic tables.

316. VALUES OF DEFLECTIONS.—Degrees or tangents of degrees are merely proportions, and we need a unit value to give them meaning. As the measurement of the deflective power of the current is obtained in terms of resistance exerted by the earth's magnetic field, this latter must be expressed in a definite value, or unit, in order to obtain the value of the current. The earth being a magnet, its lines of force converging towards the magnetic poles, of course the intensity of its magnetism is, as with small magnets, greatest at these poles; but this magnetism has two actions on our instruments, producing the *dip* or vertical deviation, § 131, and the horizontal direction, § 132. This latter

is that which is used in compasses and galvanometers and moves the needle in a horizontal plane, drawing it to the magnetic N. and S. meridian, or zero line, and would draw a single pole (were such a thing possible) along that line. It is usually written H in formulæ, and is necessarily strongest at the magnetic equator, where the natural position of the needle, or the resultant of the earth's force, is horizontal, and weakens as the pole is approached, where the horizontal motion is absorbed in the vertical. The horizontal intensity is proportional to the squares of the rates of oscillation of the needle at different places, but for full information on this subject, works treating of magnetism can be consulted. What is necessary to observe here is that any galvanometer whose *constant*, or current value is measured at one place, will require a correction when used at other places proportional to the relative horizontal intensities of the two places.

317. *Horizontal Intensity.*—This value is subject to small changes (besides the irregular ones occurring during magnetic storms), but the value usually employed is that measured in 1865; expressed in the metre-gramme absolute units that value is 1·764: in the foot-grain system its value is 3·826. These are the values symbolized by H, and they mean, that a free unit pole would, under the earth's magnetic influence, acquire those velocities in one second of time. The measurement of this value (see also § 132) can be effected by means of a tangent galvanometer and a battery of which the E M F is known, by the formula

$$H = \frac{E\, 2\, \pi\, n}{R\, .\, r \tan\theta}$$

where π is the circumference and r the radius, n the number of turns, R the resistance in ohms, and θ the angle.

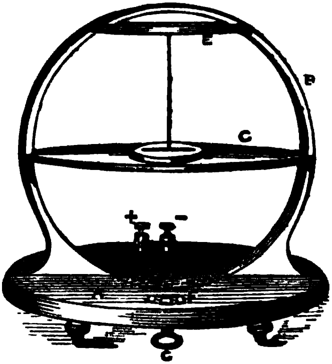
318. *Zero Line.*—The zero N. and S. line is itself not fixed, so that to make correct measurements, the galvanometer needs to be placed in the actual zero line at the time of observation. There is a small annual variation of the mean position dependent on the season, and a larger daily one, both, therefore, due to the changing position of the sun in relation to the place of observation, and probably electro-magnetic in character, and caused by the thermo-electric currents set up by the motion of the earth under the sun. According to observations made in Paris by Cassini, the amplitude of these diurnal motions is 13 to 15 minutes of arc, from April to September, and from 8 to 10 from October to March. During the night the needle is nearly at rest; at sunrise the north pole moves westerly to a maximum

between noon and 3 p.m., when it returns to the east, in both cases, as though the south pole were attracted towards the sun: these variations increase as the magnetic latitude increases. The needle occupies the mean zero position about 10 a.m. and 7 p.m.

319. **The Tangent Galvanometer.**—It is best to commence the study of galvanometers with an instrument theoretically perfect, rather than with those which are merely simple in form. The tangent galvanometer then is simply one in which the foregoing principles are carried out; that is to say, one in which the magnetic field, generated by the current, is so large that the motion of the magnetic needle within it does not materially change its relations to that field. Therefore the essence of a tangent galvanometer is simply that the coil of wire conveying the current shall be a circle of a diameter greatly exceeding the length of the magnetic needle; it should be *at least* 12 times as great. See § 328.

320. *Construction.*—The best construction I have been able to devise is shown in Fig. 53. An elliptical board A is supported by three levelling-screws, two visible and one beyond the binding-screws. The ring of wire, of which I shall speak presently, is let into this table, and supported by two blocks of wood; across its middle (a little below the centre, of course) a table C is secured which carries in its middle the dial, surrounded by a rim in which a glass cover can be placed. The needle may be supported by a steel point in the centre of the dial, or (which is far better) suspended by a silk fibre from the middle of the small piece of wood or brass E, also secured to the ring; this can be best adjusted to centrality, so as to compensate for any slight want of true levelling, by an apparatus similar to the mechanical stage of a microscope. I have shown an instrument of three circuits, thrown into action by a commutator G, working under the stand. The end of the first circuit, i. e. the stoutest conductor, is soldered to binding-screw −, the other ends are taken to three studs F, the wires being slightly let into the wood; a screw-stud con-

FIG. 53.



nected to binding-screw + carries a spring which completes either circuit as needed.

321. *Connections.*—All these wires should be kept as close as possible, so that practically they neutralize each other's influence on the needle.

By placing the connections at some distance apart in the plane of the wire, it is evident that part of the circle is partially neutralized by the wires below, leading to the conductors; the conductors themselves also will act irregularly on the needle, according to the side to which it is deflected, and, at any rate, destroy the true tangential values of the deflections. It must always be remembered that conducting wires and connections form an integral part of every electric system; we cannot confine the action just to those wires which we call the instrument proper.

322. *Details of Circuits.*—Such a three-circuit instrument may be constructed by forming a ring of the desired size, out of paper pasted up, which is best accomplished upon a disc of wood cut in two and temporarily secured to the table C; this can then be mounted on a stand for convenience of winding. Lay on forty-five turns of the finest wire to be used, say No. 20, then four of No. 16, then a complete circle of thickish copper sheet; next five turns of No. 16 and forty-five of No. 20 will complete the wires. The ends of these, coming out at the lowest point of the ring, must be so connected that the current enters by the single ring and goes to the 1 stud, or continues through the nine turns of No. 16, and then, in like manner, to stud 2 and to the ninety turns of No. 20, always, of course, in the same direction around the ring, and, finally, to 3 stud. In this way the commutator includes in the circuit 1, 10, or 100 turns of wire, and by the arrangement of winding, these being practically all at the same distance from the needle, their actions will be in that proportion, and one value will apply to all the circuits.

323. *Value of Deflections.*—The actual deflection any particular tangent galvanometer will produce with a given current, say the unit current of 1 ampère or chemic, will depend directly upon the number of turns, and inversely upon the distance of the rings of wire from the centre; this relation is derivable from the following law:—

A current of unit strength placed once round the circumference of a circle of unit radius, in the plane of the magnetic meridian, will cause a short magnet suspended at the centre of the circle to be deflected through an angle whose tangent is 6·2832, *divided by the absolute horizontal intensity of the earth's magnetic force at the time and place of observation.*

For any diameter, calling H the earth's horizontal intensity, r the radius of the coil, d its diameter, L length of wire in the coil, all in metres, n the number of turns, θ the angle of deflection, and C the current strength in absolute (metre-gramme-second) units, we have:—

$$C = H\frac{r^2}{L} \text{ tang } \theta^\circ; \text{ or } C = \frac{H}{12 \cdot 566} \times \frac{d}{n} \text{ tang } \theta.$$

The result will be expressed in metre-gramme-second units, and multiplied by 100 will give the current in ampères.

Deflections exceeding 60° are very unreliable, because of the rapid growth of the tangential scale. Even at 50° a single degree means three times as much current as at 10°, four times at 60°, and forty times at 80°, so that the smallest error in reading becomes of great importance at these large angles.

324. *Other constructions.*—In order to obviate the small errors of the single ring system, when the ring is not very large, two rings are occasionally employed, in order that the needle, being suspended between them, the errors due to its motion may compensate each other. This, however, tends to introduce another error affecting the smaller deflections, and therefore of more consequence than the other, which tells mainly upon the comparatively useless large deflections. It is also stated that the deflections are accurate if the wire is wound upon a section of a cone, of which the needle forms the apex, at a distance of one-fourth of the diameter of the nearest coil of wire. In neither of these forms is there any defined law of construction, and the chief advantage of the double ring form is that the resistance may be lower by dividing the current, and the range of power regulated by the distance of the rings. It would seem that these forms are more expensive and difficult of construction than the simple ring, and that they have small advantage over it, if the ring itself is made of a width at least equal to the length of the needle and of sufficient diameter.

An approximately correct tangential instrument can be constructed of a circular sheet of metal, about twice the diameter of the length of the needle, especially if a compound circular needle system, § 307, is employed. An instrument of this type is used in America, provided with a system of flat coils, such as are employed in ordinary galvanometers, and the excess of action of the upper sides beyond the reverse action of the lower is availed of to produce the deflections. The influence of such a system upon the magnet is largely influenced by the distance between the needle and the wires.

325. THE SINE GALVANOMETER.—In § 313 it is shown that

the pull of the earth varies as the sine of the angle of deflection from zero, its full power being exerted at 90°. The pull of the current is greatest at 0°. Hence in all galvanometers where the wire is fixed in position the deflective power weakens as the resistance to it increases, and, therefore, the resultant influence of equal increments of current is rapidly reduced, as seen § 323. In the sine galvanometer the needle is always in the line of utmost action of the current, because the coil of wire is made movable, so as to follow the needle in its deflection. Two results follow: 1. The current always exerts its full power, and, therefore, its result is collated purely to the earth's magnetism in the ratio of the sines of the angle, and, as it is no longer weakened by the deflection, there needs no allowance in the ratio of the cosine of the angle. 2. As the needle is always in the middle of the magnetic field of the wire, and never alters its position in relation to that field, any kind of construction or arrangement of the wires is equally available. As a consequence of this, and as the scale of sines is one of comparatively small differences, the measurement of currents, especially of those large in proportion to the power of the particular instrument, that is, producing deflections of over 45°, is more accurately observed than with any other form of instrument. But the actual power of the instrument is of course reduced, because the actual deflections of the needle are proportionately increased, that is to say, if the needle of a tangent galvanometer moves to 45°, and this instrument is then made to move on its centre and to follow the needle, the deflection will become 90°, or generally the deflections will be such that the value of the tangent in one case is the same as that of the sine in the other.

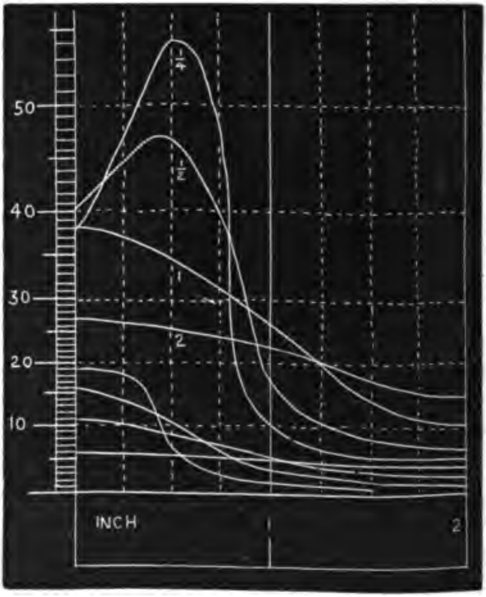
The limit of use therefore is reached with a current giving 80° or so, and for larger currents it is necessary to employ shunts.

As the needle never changes its position in the field of the current, and as long needles are most powerful, they may be advantageously used in this case; but any mode of construction is available, and any horizontal galvanometer may be converted into a sine galvanometer by placing it on a stand movable on its centre and fitted with an index traversing a graduated scale, as described § 312. All that is required is to place a stop or a small weight on each side of one end of the needle or indicator, so as to limit the motion to a degree or two. As soon as current passes, the needle moves against one of these stops, then the instrument is moved gradually on its axis till the needle resumes the normal position on the zero line. A reading is now taken of the degrees of arc through which the instrument has been turned, and the current is proportional to the sine of this reading. A single actual measure of the value, in any unit, of one deflection then gives the values of all readings from a table of sines, but, of course, variable with the strength of the earth's magnetism.

326. Ordinary Galvanometers.—Most galvanometers are composed of two flat coils of wire placed side by side, with a space between them to allow the needle to enter the chamber formed by the interior of the coils. The power of the instrument depends upon the strength of the magnetic field produced by the wire with any given current; that is to say, upon the number of turns of wire which are effective, and their degree of effectiveness. As to this, much misapprehension exists, and most electricians would consider that the position of greatest influence of the current is on the zero line, and close to the needle. But this is not the case.

327. I constructed an experimental instrument in which the conductor could be exchanged so as to constitute a single turn of wire having vertical distances of ¼, ½, 1, and 2 inches from the

Fig. 54.



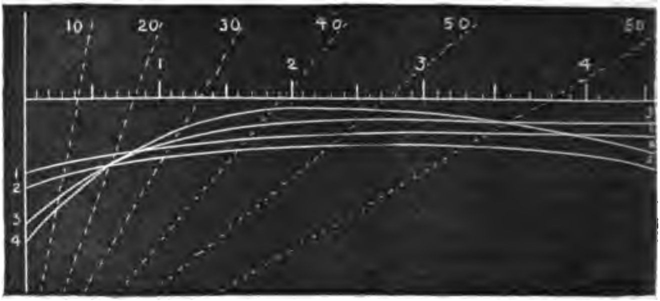
needle, and be capable of sliding horizontally to any distance from the zero line. I passed uniform currents of 1 chemic and 5·4 chemics through this, and noted the deflections through a large range of positions. For experimental purposes, I assumed that the deflections were of tangential values, and constructed a variety of curves of action, of which two sets are shown, the upper curves giving the action of the larger current.

328. It is evident that the power of the current over the needle increases as it follows the deflection. As the wire is moved out from zero, the deflection increases, as though the needle were being pushed out, until the wire is nearly over the pole of the needle. The figures show plainly that the wire is ineffective beyond a certain horizontal distance, which is smaller the nearer the wire is to the needle. The facts thus seen, the reason is obvious if we consider the magnetic fields generated. It is evident that these double coils constitute, not one, but two fields overlapping each other, and the strongest part of each field is in the vertical plane of the middle of the coil. The consequence of this is that on the middle line of the two fields they have a weaker action upon the pole of the needle than they have as the deflection increases. The action of each point of the wire upon the pole varies, in fact, as the square of its distance. If, then, we consider the action at the zero line as representing the distance 1, the effect of the two coils will be $1 + 1 = 2$; but if the position is such as to halve one distance and double the other, we have the sum of the actions $4 + \cdot 25 = 4 \cdot 25$, double the first power. Of course this is only a very rough mode of reckoning what could only be exactly represented by an elaborate array of figures. As the vertical distance of the wire increases the overlapping of the two fields increases, and the action becomes more equal, as shown in the line of 2 inches. The gradual approach of the lines to the horizontal, as the distance increases, presents to the eye the action of the well-proportioned tangent galvanometer with large coil and small needle, in which the line of current would be a true horizontal line, § 330.

329. It is evident from the curves of action that no simple law can be formulated showing the ratio of the value of deflections; yet it is certain that a law does govern them, but the formula must take into account the position of each single turn of wire. But a line can be ascertained by experiment, which fulfils in these instruments the function of the line of tangents in the more perfect form, this line being a curve varying with the positions of the wires. This (which has never before been described to my knowledge) is the plan I devised

for calibrating galvanometers. By placing the instrument in circuit with a tangent galvanometer graduated in ampères, I obtain a series of corresponding deflections which I transfer as radial lines upon a paper mounted upon a table having a large quadrant drawn upon it, and fitted with an arm working on a centre pin. Knowing approximately what the curve will be, I run a pair of compasses, open to a suitable space, over these lines, and thus obtain a curved line which can then be divided into equal parts, and which acts as a scale, several feet in length, from which, by means of the radial bar, the actual dial of the galvanometer is easily and correctly drawn. Such a set of curves is shown in Fig. 55.

FIG. 55.



330. One object I have aimed at in galvanometers is to so construct them that the action of any of the horizontal sections should be equal, and such that it should vary as the number of turns of wire occupying that section. This can only be really accomplished on condition that there is no central opening, but a consideration of the several curves, Fig. 54, will show that it will be effected whenever all the lines representing current shall inclose an equal space. Therefore, as the wire occupying, say, the quarter-inch section, has a great power in the small deflections, that power can be reduced by extending the layer of wire to a distance at which its power is small.

Of course this diminishes the actual power of the instrument, because the object is not to use the wire so as to produce the utmost effect, but to obtain a particular result. In this way I have produced circuits of 1, 10, 100, 1000 turns, which, with those resistances in circuit, would each produce a deflection of 34° with a current from the same Daniell cell.

Fig. 55 shows a set of graduation curves obtained for an instrument having four circuits, consisting of

No. 4,	..	900	turns	No. 26	cotton-covered wire.
3,	..	90	„	18	„ „
2,	..	9	„	18	„ doubled.
1,	..	1	„	sheet copper.	

The whole being continuous, this gives four circuits of 1, 10, 100, 1000 turns, so arranged as to have approximately equal actions, and give reading of current from 10 ampères to ·0001. In this instrument there was a wide opening in the middle, and the effect is shown in Curve 4, which is that of the circuit closest to the needle. Where the curve rises the current has least power. The curve shows also by its rapid fall beyond 50° that the layer of wire does not extend far enough away from the needle to equalize the field. Curve 1 shows the effect of increased vertical distance in doing away with the effect of the middle opening, and also in utilizing the outer portion of the plate of metal filling the space devoted to that circuit. It shows clearly that at a further distance the curve would flatten down into the simple tangent line, Fig. 52, which is the scale of equal parts shown, indicating ampères on Curve 1, and the corresponding decimal submultiples upon the other curves. It should be understood that an unsatisfactory instrument is here selected, because of the lessons it teaches, and because, on this small scale, good curves would run into each other too much.

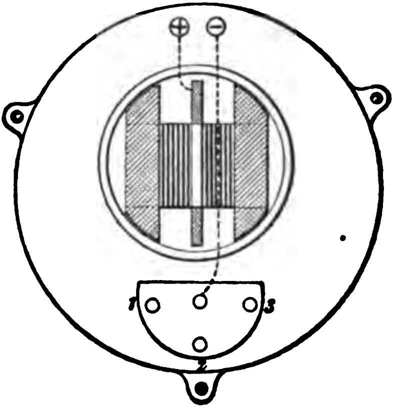
331. It is a remarkable circumstance that no electrical textbook or teacher has shown that galvanometers can show the resistance of the circuit as well as the current passing, provided the electromotive force is known. Yet many galvanometers have been made, graduated for resistance, and the system was patented by me seven years ago. As current and resistance are linked together by a defined law, they being inverse to each other, as $\frac{E}{R} = C$, and $\frac{E}{C} = R$, so also, as in a tangent galvanometer, C varies as *the tangent of the angle*, it follows that the resistance varies as the *co-tangent of the angle*. Therefore, as the line of graduation for current originates at the zero line, or at 0°, so also a true line of graduation for resistance originates at 90°, the graduation of that line depending on the E M F producing the current. Therefore, if a known and reproducible force is employed, the instrument can be graduated to show resistance in ohms as well as current in ampères. The only force at present available for the purpose is that of the Daniell cell.

332. *Sprague's Patent Universal Galvanometer.*—This is an instrument consisting of several circuits so following each other in power as to give continuous readings over a great range, and graduated to show current and resistance in the defined units, and is constructed to carry out the foregoing principles and to act precisely as a tangent galvanometer, but without needing calculations. It in fact combines within itself a series of instruments.*

333. For convenience of amateurs who may wish to construct an instrument of this kind, I describe a simple form with three circuits.

Fig. 56 represents a stand with three levelling screws; on it are fixed the coils of the galvanometer and a commutator for throwing different lengths of wire into circuit. The coils may be made in one frame on a flat copper tube, or, as is usually done, in two parts, one on each side of the needle; the sides of the frames are secured to the stand either by brackets, or if made of wood, by brass screws passing up through the stand. Even if made separate, the two sides of the coils should be mounted together on one mandrel for winding, so as to distribute the wires equally between the two. The chamber within the coils in which the magnet plays should be 2 inches long and ½ inch deep, and the frame made 3½ inches long and 1¾ inch

FIG. 56.



---

* I have one which, commencing with the current of a large Grove giving 18 ampères, measures the whole range of currents, direct and without shunts, to that passing through an illuminated vacuum tube.

high, so as to form channels or spaces in which the wire will lie, ¾ inch wide, and the same in depth all round the central chamber.

The laying on of the wire must begin in the middle, and each end must be connected so as to complete an exact turn at the middle, otherwise the indications will be inaccurate. First lay on 90 turns of No. 20 cotton-covered copper wire, leaving 6 inches out for connection: 45 turns on each side will bring the coils back to the middle line. Solder the end of the No. 20 (at the exact turn) to a double length of No. 18, leaving 6 inches of these out for the connection, and lay on nine turns of one of these wires in each channel, so as to divide the current between them. Finish with a strip of copper ¾ inch wide joined to the 18 wire, at the exact spot completing a turn, and leave the ends of the wire standing out for connection; make one turn of the strip and bring out, on each side, a wire soldered to it, for the commencement of the coils. This will give three circuits with decimal ratios (nearly) to each other. The wire ends are to be carried through the stand, and led to the required points. The two outside ends are taken as one (dividing the current) to the binding screw +; the next pair of No. 18 representing one turn round the needle, are taken to 1 of the commutator; the next pair are taken to 2, giving 10 turns; the first end of No. 20 wire which completes 100 turns goes to 3.

334. The commutator is similar to the one used frequently on medical coils, a central pillar connected to binding screw − and a spring from it traversing over the numbered studs. For some reasons it is better to use mercury cups thus; a block of hard wood an inch thick has central and radial holes ¾ inch deep by ¼ inch bored in it, and when fixed on a stand, holes are bored through just large enough to pass a No. 12 copper wire, on which a head has been hammered up. These heads are well amalgamated, and a piece of wire bent twice at right angles passes from the central cup to the one desired to be used; the resistances are thus kept very small, so that when used for measuring batteries, &c., they may be ignored in many cases. This is the form shown in Fig. 56; if studs and a radial spring are used, the positions would be reversed; or they may be placed under the stand, and the arrangement of the levelling screws altered. See also § 398.

All the connecting wires should be kept as close as possible to the middle line, so as to have little effect of their own upon the needle and neutralize each other.

The needle is 1⅞ inch long, of four strips of watch-spring, and may be fitted with an indicator and mounted in either of the ways described § 308, so as to play within the central space; if mounted on a point a long needle may be fixed in a piece of brass and screwed up through a hole in the stand and in the middle of the coils, with its point somewhat above the level of the frame. On the frame is secured a dial of cardboard, with an opening in the middle to pass the needle through, and a glass cover should go over all.

335. The graduation can be effected as before described, but the following values will approximate to the readings, if made exactly as described:—

Chemics.	Degrees.	Chemics.	Degrees.	Chemics.	Degrees.	Chemics.	Degrees.
1	11·3	5	43	9	58	30	79
2	22	6	47·5	10	60	50	83·5
3	31	7	52	15	69	100	86·5
4	38	8	55·5	20	73		

These figures represent the indications on No. 1 circuit: when No. 2 is employed they are to be divided by 10, and by 100 for No. 3. By using finer wires more circuits may be used, but the size of the frame must not be increased, and the whole space must be filled or the ratios will not hold good.

336. Vertical Galvanometers.—For many purposes it is common to arrange the needle in a vertical plane mounted on a central pivot, in which case the needle is double, one working inside a coil, the other with its poles reversed working outside. Such an instrument—which is, in fact, the needle telegraph instrument—has its uses, but its indications cannot be relied on; they vary with the varying magnetism of the needles, because the resistance to motion is not the magnetism of the earth but the extra weight of the lower parts of the needles; the chief advantage is their instantaneous action, as the needle does not vibrate as in the horizontal form, and their ready visibility from a distance, which specially adapts them for use as mere indicators in a circuit, as in § 298.

The sensitiveness may be increased if the axis of the needles is pointed at the back so as to work in a cup, by inclining the instrument, and so diminishing the height through which the weight has to be lifted for a given deflection. This form is frequently used in practical operations, such as testing telegraphic wires, from its portability and general handiness, and in such cases it is usually made with a double wire so as to be employed as a differential galvanometer. The construction is the same as that of horizontal instruments, the difference being in the mode of suspending the needles and the mounting in a case.

337. **Differential Galvanometers.**—These may be made in any form of construction. They consist of two exactly similar wires wound side by side throughout, but very carefully insulated from each other: they must have exactly the same influence upon the needle, and must also have exactly the same resistance. To secure the first, care must be taken that the wires are equally tightly laid, so that one has no greater length at any part than another. The wires should make half twist at each layer, so that they shall be alternately the nearest to the needle; if this precaution is not taken, and a needle suspended by a fibre is used, the needle is apt to be drawn bodily towards one side, and to be deflected in opposite directions according to the side it is drawn to, in which case no reliance can be placed upon it, as the least change of level will cause it to turn either way with the same currents. For this reason, probably, differential galvanometers are usually made with pivoted needles, thus lowering their sensitiveness. To test this equality of action the two coils are to be connected at the one end, so that the current goes by one and returns by the other; no deflection should be produced, however strong the current. If any effect is shown, it may be corrected by adding one or more turns of one wire, or if this gives over-correction, then by unlaying a part of the wire having least influence and laying it again in its place somewhat loosely so as to lengthen it. The equality of resistance may then be tested by connecting up the instrument so as to divide a current between its two coils with reverse action, and adding wire at one of the connections outside the coils to the wire having most effect until they exactly balance, or the resistances may be equalized by means of the bridge, § 407.

A differential galvanometer may be employed as a single circuit of alterable resistance and powers, as one circuit may be used alone, or the two coupled as one, reducing the resistance to half of that of a single circuit: or they may be used in series with double the resistance but double the action on the needle, each of which arrangements suits varied conditions of resistance in the rest of the circuit; such an instrument is therefore of use with the Wheatstone bridge.

338. A good differential galvanometer enables resistances as well as currents to be compared on principles similar to those explained, § 399. If the two coils are exactly equal as directed, currents may be compared by passing them in opposite directions. Two resistances may be compared by putting one in each circuit, and then connecting to one battery so as to divide the current between them: if one is a resistance to be measured and the

other a resistance instrument, by altering the latter till there is no effect upon the needle it measures the first resistance. Multiplying ratios are given to the instrument by means of shunts, § 460. These are provided to one or both the circuits in such way as to open other paths to the current and allow $\frac{1}{10}$ or $\frac{1}{100}$ of it only to pass the coils; then the actual resistance inserted in the other circuit has to be multiplied by 10 or 100 to give the resistance which it balances.

In using these instruments, when the resistance to be measured is equal to or greater than that of one of the wires, the resistance and rheostat should be inserted in the circuit as described: but if the resistance is less, it is better to couple the two circuits so as to neutralize each other, and to use the rheostat and resistance to be measured, as shunts, one for each circuit.

339. THOMSON'S REFLECTOR.—This valuable instrument is so purely technical in its uses, and scarcely employed except for delicate telegraphic purposes, that a full description is hardly required here, especially as it is rarely likely to be made by any one not familiar with it. It is usually constructed upon a vertical brass plate about $\frac{1}{4}$ inch thick, securely mounted by pillars upon an ebonite stand. In the plate and upon each side of it are turned circular recesses, leaving a thickness of less than $\frac{1}{8}$, the centre of which is also entirely cut away, as well as a vertical space in which hangs the needle system. Four reels, about $\frac{3}{4}$ inch wide and of 2 to $2\frac{1}{2}$ inches diameter, of brass or ebonite, with a central tube of $\frac{1}{2}$ inch bore, contain the wire, and are made to fit into the recesses of the plate and held there either by large headed screws or by turning small catches so as to grip the edge of the reels. The coils are connected in pairs, leaving four ends which are connected to binding-screws, so that if the coils are exactly alike and carefully adjusted they may be used differentially, or at any rate be connected variously as described § 337. In some cases also there are double wires used to make the instrument a truly differential one. According to the purposes desired, different sized wires are used; but fine wire (No. 40) is generally used, and a resistance of 8000 or 10,000 ohms laid on.

The needle system consists of two pieces of watch-spring $\frac{3}{8}$ inch long, cemented upon an aluminium wire so as to occupy the middle of the coil tubes: on the upper needle is also cemented a mirror made of a microscopic cover silvered and inclined so as to reflect a little upwards, and a slip of mica is fixed across the lower needle so as to act as a damping vane, and limit the play of the needle. At the top of the supporting plate, and in a hole drilled exactly down the central line, is a sliding wire with a hole in its lower end to which is hooked a silk fibre attached to the aluminium rod of the needles: this fibre should have as much length as possible given it, and by slightly raising or lowering the rod the needles can be properly arranged for work, or lowered so as to take their weight off the fibre when moved about; this needle system should weigh altogether only 3 or 4 grains. The mirror is sometimes made somewhat concave, so as to concentrate the light at a given focus.

The instrument is covered with a cylinder of glass with a flat brass top, from the middle of which rises a brass rod fitted with a tangent screw to move it gently round. The rod carries a sliding tube on which is fixed a curved magnet, by altering the position of which the needle is controlled, as to delicacy by the height of the magnet, and as to position by the line in which the magnet is placed, so as to supersede the small directive action of the earth upon the nearly astatic needle system, which is powerfully controlled by this magnet owing to its greater nearness to the upper needle.

340. *The index* is the beam of light reflected by the mirror from a lamp placed behind a screen 2 or more feet distant: usually a narrow slit is provided which thus sends back a narrow line of light: it is much better to use a ½ inch circular opening with a vertical wire (which should be a dead black) stretched across it: this reflects a black line crossing the graduation, surrounded with light enough to enable the graduation to be observed. The light is improved also by being placed some distance back, with a reflector and concentrating lens adapted to the distance of the mirror, so as to get a bright spot which does not require so much darkening of the operating room.

The screen has upon it a scale of equal parts mounted on a slide for adjustment, and the whole is to be so arranged that the indicating line or spot is upon the zero line, and is equally deflected to either side with reversed equal currents. The best screen is one of glass made translucent by grinding or by means of suitable varnish, upon which the scale is engraved. This form of scale is placed between the observer and the instrument, and should have a framework of black cloth around to throw it up; it can then be used in diffused daylight.

The deflections within the small limit of play allowed are proportional to the tangent of the angle of deflection, and, consequently, to a straight line divided into equal parts forming the scale: an absolute value can be given to the deflections, as with the tangent galvanometer, by ascertaining the value of one deflection; but this value will only hold for the same distance of the scale, which distance can therefore be adjusted so as to bring the unit deflection of, say 100 parts, to some decimal submultiple of the ampère.

341. *A shunt* is always provided with the instrument so as to send $\frac{1}{1000}$, $\frac{1}{100}$, $\frac{1}{10}$, or all the currents into the coils: by using these as accuracy of measurement is approached, observations can be made without throwing the needle about too violently. The instrument must be absolutely steady, and therefore fixed upon a brick pillar, or upon a shelf fixed on a solid wall, otherwise the spot of light is always dancing about, and it is impossible to make any useful observations.

342. GERMAN SILVER WIRE.—For purposes requiring a high and constant resistance galvanometers are best made of German silver wire, owing to its small variation of resistance by temperature. But this only relates to external temperature: as relates to the heating effects of the current itself German silver wire is worse than copper, and therefore variations in the ratio of shunts will be greater with it than with copper. German silver increases its resistance only about $\frac{1}{9}$ as much as copper, but a wire of the same size would have 12 times the resistance, and therefore collect in it 12 times as much heat from the passing current. German silver wire is most useful in a galvanometer intended to measure electromotive forces by the process described § 506, in which a high resistance is needed and one uniform in all experiments. Brass wire may also be used for the same purposes. But for all ordinary purposes wire of the very highest conductivity should be employed.

343. RESISTANCE OF GALVANOMETERS.—It is usually stated that the best conditions for a galvanometer are that its resistance should equal that of all the rest of the circuit. This like the similar statement as to batteries, is apt to mislead. *Resistance as such has nothing to do with the matter*; it is always a disadvantage, except for special purposes as just noted. But resistance, in wound-up wires, carries with it the number of turns of wire, and consequent power; therefore in a given space for coils of wire, that space should be occupied by stout wire in a circuit of small resistance, because fine wire would introduce a useless resistance; with a circuit of large resistance fine wire must be used in order to get sufficient effect. But a fine wire instrument can be utilized by means of shunts, § 341, which divert part of the current from them, reduce their sensitiveness and also the resistance of the circuit.

344. There have been a great variety of galvanometers introduced of late to suit the growing applications of electricity:

such are those of Marcel Deprez, in which a powerful magnet is used to inclose the coils and produce the magnetic field in place of the earth's magnetism. Messrs. Ayrton & Perry have also adopted this plan. I do not attempt to describe these instruments because I have preferred to give the general principles very fully, so as to enable students to make for themselves such forms as suit their purposes and powers. Particular constructions can generally be examined, and are easily understood when the principles are well mastered.

345. Measurement by Chemical Action.—Faraday proved the fact that, whenever an electric current passes through a compound in a liquid condition (whether fused or in solution) the substance is broken up, its constituents separated into two parts, one of which appears at the positive, the other at the negative pole. The laws of this action are studied Chapter IX., under the name of Electrolysis. This chemical action is proportional to what is called the "quantity" of electricity circulating; hence any such chemical action capable of ready measurement may be made the means of measuring the galvanic current which effects it. The process commonly used is the decomposition of dilute sulphuric acid, usually, but erroneously, termed the decomposition of water, because the constituent gases of water, H_2O, are set free.

346. Voltameters.—Instruments for this mode of measurement are thus named. Their form is subject to infinite variation, for all the essentials are the two conductors, an outlet for the gases, and a means of measuring them, either separately or together. The great drawback to these instruments is that they not only present a considerable resistance, but in the case of gaseous decomposition also create a *counter electromotive* force, § 254, which needs a force equal to one Grove's cell to be employed solely in working the voltameter. The electrical *resistance* proper is a matter of size of plates, which must be arranged to be proportionate to the current they are intended to pass: this cannot be controlled as in galvanometers by shunts, because of the counter E M F which acts as a variable resistance in the cell. For general use the plates should be as large as is convenient, and they should be platinized to facilitate escape of gas. Platinum is used because it is not acted on; carbon would answer, but for its tendency to absorb the gases; and the action noticed § 293 unfits it for use as anode with currents of large density.

347. A simple form may be made from an ordinary wide-mouthed bottle. Two plates of platinum with wires attached are mounted on the cork with binding screws outside; in the

middle of the cork a glass tube is fitted to carry off the gas by means of a flexible tube to a measuring jar: the end of this tube should project a little within from the surface of the cork and be cut off slanting so as to resist the ingress of moisture, and the cork should be boiled in melted paraffin.

If it is desired to collect the two gases separately, the cork should be fitted with two glass tubes as large as it will admit and going nearly to the bottom of the bottle. The tubes should be left open at the bottom, and closed at the top with a cork fitted as before with a gas leading tube and a strip of platinum: these giving off each its proper gas within the tube, completing the liquid circuit by the open ends dipping in the liquid.

For experiments with very small currents, as with induction coils, large surfaces are objectionable, as so much gas is retained by them and in the liquid: for such occasions a wire inclosed in a glass tube melted to it and exposing only the end, is used. These may be fixed in tubes and used as just described, or both may be passed through a cork in the neck of a small bottle with its bottom cut off, in which two small test tubes can be inverted over the conductors, so as to make a model of one of the common forms of voltameter.

348. As before stated, these instruments are objectionable on account of their great resistance. It is, however, quite possible to have a voltameter which shall not give resistance, but shall help the current. A Smee cell is to all intents a voltameter, if we collect the gas given off, and ascertain how much of it is due to local action; the mode of effecting this is described § 181: a cell for this purpose should be large enough to transmit the current freely, and its outlet should be closed when not in use, so as to keep the liquid charged with gas.

349. We have now to learn what the measure of gas given off teaches; a point which electrical writers usually fail to clear up, because they deal only with the actual measure itself, and thus base upon it all sorts of arbitrary units, as, for instance, Jacobi's unit of current, that which in one minute generates one cubic centimetre of mixed gases at 0° C. and 760 mm. barometer; or a cubic inch of gases.

But what we really want is to know what *measure* of gas corresponds to such a definite system in weights as furnishes the unit or "chemic" current; to value the indications of the voltameter as in § 316 those of galvanometers are valued. By the system of weights the current is measured by the number of equivalents of any substance acted on, ascertained by dividing the total weight by the known equivalent weight. Now the system of measure is still more simple, for every atom of a simple substance, or still more inclusive, every molecule of any substance, simple or compound (with a few exceptions), occupies in the gaseous state the same volume, no matter what its weight is. What we want is the relation between the equivalent weight and this molecular volume.

In water, H_2O, there are three atoms, all of equal volume; but as to weight, hydrogen being unity counts 2, and oxygen by its atomic weight 16, makes the molecule of water 18, which answers to two electric equivalents. Once we know then the measure or bulk of 1 grain of hydrogen, we know the weight of the same bulk of every other gas of known constitution.

The best mode of measuring gases is by the metric system reckoned at 0° C. temperature (freezing) and 760 mm. barometer (one atmosphere) correcting to actual temperature and pressure; but as exact accuracy is never attainable in this particular case, because part of the gases is absorbed, it is near enough to take the average condition at 60° Fahr. and 30 in. bar., at which, according to Miller, 1 grain of hydrogen occupies 46·73 cubic inches, which may be considered the unit or atomic volume.

Therefore, each unit of quantity or current will give off—

In the Smee voltameter, 46·73 cubic inches of hydrogen.

In the double voltameter, 46·73 cubic inches of hydrogen in one tube, and 23·37 of oxygen in the other.

In the single-tube voltameter, 70·1 inches of mixed gases.

A tube of glass, such as the ordinary Mohr's alkalimeter, can easily be graduated to measure this off direct: 46·73 C. I. = 11797·45 fluid grains, therefore a tube containing 1179·8 grains divided decimally would contain one-tenth of a unit, and require one hour to fill by a chemic current from a Smee voltameter.

One cubic inch is equal to 16·387 cub. centimetres. Of course a coulomb of electricity or an ampere current for one second being the chemic × 5·68 ÷ 36000 is represented by cubic inch ·007373, or the "ampere hour," § 386, by cubic inches 26·54 of hydrogen.

350. As any one of the reactions which take place in a galvanic circuit will answer for the purpose, the best voltameter for many purposes is two plates of copper in a coppering solution; or a Daniell with flat plates, in place of a separate cell, will supply instead of absorbing energy. The weight of copper divided by 31·75 gives the number of units of electric action, and by the proportion of time occupied to the unit time of ten hours gives the current in chemics. In this way the value of one or more deflections of a galvanometer can be ascertained and its graduation effected, instead of by the formulæ given § 323.

351. **MEASUREMENT BY HEATING EFFECTS.**—Whenever current

passes through a wire it meets a certain resistance, in overcoming which equivalent energy is converted into heat, and the current, therefore, is capable of measurement by this heat. As an illustration of the erroneous nature of the older ideas, such as that heat is the two supposed electricities, united, it must be understood that this conversion into heat of the energy of a galvanic current does not in the least reduce the "quantity" of the electricity; that is to say, a current arising from the consumption of one unit of zinc will deposit exactly the same quantity of copper, viz. one unit, whether it passes directly to the coppering cell, or whether a long fine wire, in which heat is developed, is also interposed in the circuit; the only difference will be that it will take longer about it. This is explained by the general principles of the circuit, § 440.

352. Experiment, has, however, settled that—(1) In a wire of given resistance (ignoring the variation produced by the heat itself in the wire), equal currents always generate the same amount of heat. (2) With different currents the amount of heat varies not in the ratio of the currents themselves, but in the ratio of the squares of the currents; thus, if a current of one unit produces in a given wire one heat unit, that is, sufficient to raise one pound of water one degree in temperature in a minute —then a current of two units will produce in the wire four such units of heat.

This is expressed mathematically $H = C^2Rt$; to give the heat developed in a given time any fixed value, a constant which is the heat equivalent of the current in a unit resistance for a unit time (such as one second) must be employed with the formula; for which see § 390.

In heating wires, it is to be remembered: (1) The same *current* will heat an inch or a mile of the same wire; the *length* heated in any given conditions is purely a question of resistance, and the force employed to pass the current. (2) To heat, equally, thicker wires, the *current* must be increased as the weight of wire per foot increases.

The arrangement of batteries to produce these two effects is number in series for the first, large cells for the second; and the resistances and electromotive forces must be arranged so as to produce the required current.

353. CALORIMETERS.—These little-used instruments are thermometers containing a platinum wire, through which the current passes. There are two kinds: (1) an air thermometer—a bulb with a fine graduated stem containing liquid; the platinum wire crosses the bulb: (2) a vessel containing a known weight of a non-conducting liquid, such as water or alcohol, the wire

passes through this and a thermometer shows the temperature generated, which, with the specific heat of the liquid, gives the actual heat, expressed as a quantity. Thus, if a pound of water is used, each degree represents a unit of heat, and if the resistance of the wire is 1 ohm the calculations are very simple.

354. HEATING EFFECT UPON WIRES.—The formula in § 352 expresses the actual heat as quantity of energy; but another consideration of moment is the temperature to which that quantity of heat can raise a particular wire. This depends upon several considerations, such as the weight of metal in the wire, and the specific relation of the metal itself to heat (see §§ 12, 155, and 355), i. e. its specific heat. A general formula may be given, not reckoning, however, the heat lost by radiation and conduction, § 489.

C = Current in ampères.
R = Resistance of wire in ohms.
W = Weight of wire in grammes, see § 356.
s = Specific heat of metal.
H = Rise of temperature per second in degrees Centigrade.
$\cdot 24065$ = Calories equivalent to ampère, see § 390.

Then

$$H = \frac{\cdot 24065 \times C^2 \times R}{W \times s}, \text{ or } \frac{65\cdot 99\, C^2 R}{W \text{ (grains)}} = \text{Copper Deg. Fahr.}$$

355. The *specific heat* of metals increases as they approach the temperature of fusion; and, therefore, platinum varies less than other metals. The following figures are the average between 0° and 300° C.

	Specific heat.	Melting point. Deg. Centigrade.	Specific gravity.
Copper	·1013	1091	8·9
Iron	·1218	1805	7·8
Silver	·0611	1023	10·5
Platinum ..	·0355	2100	22·1
Zinc	·1015	412	6·9
Lead	·0314	620	11·4
Graphite ..	·2018	?	1·6

The *specific heat of alloys* is the mean of that of their components, and is ascertained by multiplying each specific heat by the percentage of the metal and dividing the sum of the whole by 100. This only holds good at a distance from the melting points, which are usually not the mean of the constituents, but lower; and it is doubtful if it applies to those alloys which, like German silver, differ in resistance greatly from that of the means.

356. The effects may be compared upon the system of English

weights and units used in these pages, by taking, as the heat equivalent, the grain instead of the pound of water. Then the worth of the ampère current is 6·6855 such grain degrees Fahr., and that of the chemic $(5{\cdot}68)^2 = {\cdot}20722$ per second, which figures may be used in the above formulæ to replace ·24065, the weight being expressed in grains instead of grammes.

The length in feet of a wire weighing 1 grain per foot, which gives 1 ohm resistance, is of course the weight in grains, and is for copper 4·845 and for platinum ·2828, and in these different lengths or weights equal *actual heat* is produced; but it will be found, when the specific heat is taken into account, that very different *temperatures* result.

If we multiply the unit heat of current 6·6855 by the reciprocal of the specific heat (that is 1 ÷ specific heat), we get the number of grains of the metal that unit heat would raise 1° Fahr., and dividing this by the length of the grain-foot ohm unit wire, we get the actual rise of temperature produced in that wire for an ampère current as 14·5° for copper and 730° for platinum; that is, a current which would only warm a grain-foot copper wire slightly would raise a similar platinum wire to a red heat. Further information will be found, chap. vii., on resistance.

357. In an experiment with such a platinum wire, I obtained the curious result that the loss of heat and gain so balanced each other that the actual temperature maintained by the current closely corresponded with the calculated rise: but of course, the coincidence noted was accidental, and only holds for very fine wires.

HEAT OF WIRES.

Heat observed = to Degrees Fahr.		Current in chemics.	Calculated heat.
1. Ampère current		5·68	730
2. Faint red	1000 1300	7·	1109
3. Cherry red	1400 1800	8·	1473
4. Orange	2000 2200	9·5	2042
5. White	2350 2700	10·7	2585
6. Fused. .. .. about	3700	12·6	2847

The last line of the experiments illustrates the fact that the breaking of a wire by the galvanic current is not due to pure fusion, but occurs at a lower temperature. The effect is partly analogous to the destructive effects of lightning. The fusing point is, in fact, that point at which the vibratory molecular motion of heat, § 32, just overcomes the molecular attraction of cohesion; but, if electric transmission also involves a motion or revolution of the molecules, it is obvious that this effect must be added to that of heat, and destroy the cohesion at a lower temperature.

358. COULOMB-METERS.—This is a new class of measuring instrument called into existence by the probability of the distribution of electricity from central sources. They are registers of the quantity of electricity which may have passed through a circuit in a given time, acting in fact like the gas-meter. They are divisible into two sections.

359. *Magnetic.*—In these the action of the current in generating electro-magnets is brought into play in a variety of modes. In some, such as those of Lane Fox and Boys, a wheel is caused to traverse along a rotating cone which gives it motion by friction at a varying rate, according to its position on the cone, which position is controlled by the electro-magnet; this varying motion of rotation is communicated to a recording train. In others an electric motor driven by the current is checked by a resistance, such as expanding vanes. Of these a simple typical form is Hopkinson's, in which the motion is resisted by an ordinary centrifugal governor, which offers a resistance proportioned to the square of the rate of rotation, and so tends to cause the actual rate of rotation to correspond with that of current passing.

In some cases, by combining a clock or other means, the quantity of *energy* instead of *electricity* is recorded. But all these instruments are out of the scope of this work.

360. *Chemical.*—These are of two forms. Mr. Edison passes a portion of the current, by means of a shunt, into an electrolytic cell, preferably plates of amalgamated zinc in sulphate of zinc, and at suitable intervals removes and weighs one of these plates, calculating therefrom, by the deposit of zinc and the shunt ratio, the quantity of electricity which has passed the circuit in the interval. This is of course simply the process described § 350 and long ago employed by electricians for experimental operations: it cannot properly be called a meter, because it gives no indications; but Mr. Edison uses two cells with different shunt ratios, so that the weighing of one may serve as a check upon the other.

361. In a patent dated 22nd November, 1878, I described a meter which I had devised several years before, based upon the

deposit of metal, such as copper in sulphate of copper, and said, "I use two plates of the metal, and cause each to become alternately the anode when the other plate has lost so much weight as represents the unit of current employed, under well-understood laws; and I cause this change of direction in the current to be effected by the weight of metal passed from one plate to the other." I described the plates as "supported by spiral springs, or in any equivalent manner which will permit them to descend and rise according to their relative weights." I showed electro-magnets, with a rocking armature between them, drawn over to either side, according to which magnet was in action, and these magnets set in action when the descent of one of the plates closed a contact fixed at the proper point, and said, "these points and the armature therefore constitute a *reversing commutator*, and other modes of effecting the purpose may be used:" then "the motion of the armature is caused to move a ratchet wheel one tooth, and by this means to record, in well-understood manner, the number of reversals of current, each of which represents a definite quantity of electricity passing." I described the use of shunts to send a definite part of the current into the cell, and said, "the essential point of this part of my invention is the production of motion in a set of wheels by the agency of plates of metal alternately dissolved and deposited on."

362. On the 27th October, 1880, Mr. Edison patented what he called his Webermeter, which was described by Count du Moncel in the *Lumière Electrique*, as very ingenious and the most interesting of the accessories of his exhibit at the Paris Exhibition of 1881. This instrument, according to the specification, "consists broadly speaking, in using balanced plates in a depositing cell, so arranged in connection with other devices that the deposition of metal causes an overbalancing, which sets in operation registering devices and devices reversing the circuit through the cell;" further, "instead of a balance arm from which the plates are suspended, a spring balance may be used, the plate as it becomes loaded acting on a spring to make the necessary circuit connections at the predetermined point." The essential claims are: "(1) An electro depositing cell in which each plate becomes alternately anode and cathode. (5) The combination of a decomposing cell, balanced polar plates therein, and registering apparatus, and means for reversing the direction of the current through the cell, the register and reverser being controlled by the overloading of either plate."

363. The only difference between the two is that Mr. Edison prefers to cause the reverser to be actuated mechanically by the

actual weight of metal, tipping over a lever, while I prefer to effect this reversal by a momentary current through the electro-magnets. In a paper read by Mr. Shoolbred before the Society of Telegraphic Engineers, 22nd February, 1883, he suggests that "the mechanical operations involved in the reversals of the current and in their registration, absorb a large amount of power." Whatever may be the case in the Webermeter, it is pretty certain that a current working a small electro-magnet for possibly one second per hour can bear but an infinitesimal ratio to the real work of the current.

364. In later improvements I have entirely done away with all supporting agency, using a single electrode floating in the liquid, and actuating the moving parts at its limit of descent and rise. I have also arranged it to actuate other apparatus, such as cutting off the current or ringing an alarm when a definite quantity has passed, as in charging a secondary battery, or depositing say an ounce of gold on a surface; and I have also applied the generation of gases and other electrolytic actions to purposes of measurement: but their description would take up space to be more usefully occupied.

365. PRINCIPLES OF MEASUREMENT.—Measurement really means ascertaining how many times a fixed unit is contained in the thing to be measured. Originally no doubt some familiar object was taken as the unit, such as the average barley-corn, or some recognized "stone," and these arbitrary weights, &c., naturally grew up to larger ones by the process of doubling, and hence was gradually generated the present system of weights and measures. The intolerable burden of the calculations these inflict upon commerce must ultimately induce even "practical" England to get rid of them, as the more scientific and generalizing French mind has long ago.

Exactly the same process has been followed in scientific matters; before the whole aspect of science had burst upon the mind of man, the more salient phenomena of each branch of knowledge were first observed; subsequent observations were referred to and compared with these, and thus grew up a set of merely "practical" systems of measurement based upon isolated facts, and even worse, expressed in the confusing system of common weights and measures. Hence, in electricity we have such measures of action as that referred to in § 349, and many similar ones, all based on isolated facts. As electricity assumed the state of an exact science, and was brought into subjection to mathematics, the evils of this system became so intolerable that an effort was made to remedy the nuisance, and an organized system of electrical measurement was devised by a committee of the British Association and generally accepted. At the Paris Exhibition of 1881 this system was discussed by an international committee and, after some changes in the names of the units and the addition of some further units, was accepted as the international system of electric measurement.

366. Unfortunately this system, perfect as it is in itself, retains the original defect of being based upon a merely arbitrary and accidental unit, the metre, nominally a fraction of the circumference of the earth, instead of seeking a truly scientific starting-point. This evil, which very few people even yet comprehend, is analogous to the errors of the old astronomy: it looked at the universe from the earth, and tried to bring all the observed motions into a system subordinate to the earth; hence inextricable confusion. As soon as man adopted nature's centre and looked at the universe from the sun, all confusion disappeared, and perfect harmony and simplicity were at once presented to the observer. Exactly so with every other science. When we want to weigh and measure nature, her forces and works, we ought to take for our units *measures which nature herself uses.* Of all the sciences, however, chemistry alone does this, and in consequence has made the most rapid progress, since this plan, otherwise known as the atomic theory, has been employed; for what is the atomic theory but the substitution for the incomprehensible and unmeaning relations of pounds weight or pint measures of matter, of the idea of *nature's unit, the atom of matter without reference to weight or size*, except when these are required for practical purposes, and then ascertaining the weight of each form of matter which nature has put into her unit of each element? More advanced chemistry has found that gaseous volume, rather than weight, furnishes the best starting-point for the atomic system. Now volume and weight are related to each other in the metric system, but again by the purely arbitrary (though practically convenient) intermediary of *water:* but water volume has no relation to the natural atomic system, while the volume of gaseous hydrogen has, and this relation would have furnished us, after some trouble in defining it, with a perfect system of universal measurement.

That brilliant chemist A. W. Hoffman saw the value of such a relation in chemistry, and proposed as unit the *crith*, one litre or cubic decimetre of hydrogen at 0° C. and 760 mm. pressure, weighing ·0096 of gramme. Either this or the cubic metre, 89·6 grammes, would furnish a true natural starting-point for a general system: as pure gases double their volume with a fixed quantity of heat, this quantity would be the heat unit; as in doubling volume the weight of the atmosphere is lifted, that weight would be the work unit; as the same quantity of heat would raise the gas to a certain temperature, if it was prevented from expanding, it would give us a scale of temperature (if desired, one starting from absolute zero); and thus we should have the natural relation of heat and work in one unit, related also to the energy absorbed in chemical and molecular changes. But beautiful as this system would be, it is now unattainable, and we must make the best of the system at our disposal: it should however be understood that it is this fundamental defect of the accepted system which has compelled me to use my own or the "chemic" unit in this work wherever I have desired to make the natural relations of electricity intelligible. I have not retained that unit for any fanciful reason, or because it is my own, but simply because I could not exchange it for the ampère without wholly destroying the special feature of this book, viz. the treating electricity as a natural force connected to the equivalent, molecular, and atomic constitution of matter, instead of a purely artificial offspring of algebraic symbols.* It may be clearly recognized that the accepted system is also a natural one, in this sense, that it is based upon *energy*, while it ignores matter and its constitution: energy can be measured by any arbitrary units of mass, space, and time; the misfortune is that the unit of mass is not an atomic unit, and consequently the derived unit of electric quantity and current is not correlated to the chemical system of nature, except by a fractional value, as shown § 386.

367. THE B.A. SYSTEM.—This may be studied on two distinct plans, the *theoretical* and the *practical*; the latter being derived from the first. It is of great importance to clearly understand both, and their relations, but they actually constitute two wholly distinct systems, and many people can clearly understand and employ the practical system who find the theoretical one wholly beyond their comprehension. I shall therefore endeavour to so present the subject as to keep the two systems distinct, while exhibiting their relations. The mathematical expression of the phenomena of electricity known as Ohm's law, is now universally accepted, and thoroughly

---

* The same remark applies to my use of the *equivolt* unit of energy. It is not likely that either of these units will be actually employed in place of the ampère and joulad; but they serve a purpose these cannot fulfil, and they at least give us "constants" for converting the ordinary units into electrolytic work. Indeed, it is probable that corresponding units for this very purpose will have yet to be added to the B.A. system, but if so, such new units would, of course, be based upon the gramme weight instead of upon a grain system.

satisfactory; it is entirely independent of any theory whatever as to the nature of electricity, but merely expresses the conditions of the observed facts; and to do this embodies them under certain heads. The fundamental idea is that *a force*, be it what it may, produces the observed effects; this force is concerned in all operations of mechanics, &c., and in electricity is represented by "attraction," § 74. Its necessary first consequence is a pressure or pull, tension, § 75, and a *tendency to action* called "Potential," § 76, which in dynamic electricity becomes "Electromotive force," § 168, which is symbolized in Ohm's formulæ by E. This is opposed by the various circumstances, molecular construction of the substances, insulation, &c., all of which are embodied in the general term "resistance," symbolized by R, § 169, which again simply expresses a fact, but no theory whatever. The result is action measured by the relation of these two, and called "quantity," Q; and when time is taken into consideration it becomes "current," or quantity in a given time, symbolized by C. This is very commonly called "intensity of current," and symbolized by I; this mongrel term, derived from the translators of the French phrase "intensité de courant," strength or amount of current, leads to great confusion of ideas, because intensity has in the earlier English books a distinct meaning which corresponds to E M F, and has no connection with current or quantity. The object of the B.A. system is to furnish a defined unit for each of these mathematical expressions, so that all the actions of electricity may be capable of exact definition and comparison with mechanical work.

368. ABSOLUTE UNITS.—A system of absolute units is one which does not consist of arbitrary, independent measures, but is based upon measures which are common to all kinds of operations; upon the fundamental elements, time, length, mass, &c., which enter into all physical operations. Any units might be used, such as the foot, pound, second, and for many purposes these are very convenient and have to be used; but for systematic purposes the necessity of the case limits us to some form of the "metric" system, which must inevitably supersede in time all other systems of measurement, even though these latter may be proved to have points of superiority.

369. FUNDAMENTAL UNITS.—Before entering on the electric measures, it is necessary to understand the general system of which they are a branch. The fundamental elements, of which unit measures are required, are Length, Time, and Mass; of the first, two units are employed, the metre and the centimetre. The first has many advantages, but the second is being forced

into use by the mathematicians, on the ground that the cubic centimetre of water furnishes the unit weight, the gramme. As it has been fully developed, and its units have received definite names, the centimetre system will be used here. Its fundamental units are:—

L, Length	1 Centimetre.
M, Mass	1 Gramme.
T, Time	1 Second.

from which it is called the centimetre-gramme-second, or C.G.S. system.

370. DERIVED UNITS.—From these are derived the general mechanical units: of motion, which is length traversed in unit time; velocity, which is motion in unit time; momentum, which is mass having unit velocity; force, which is a general expression for any cause which generates velocity, but for systematic purposes is defined as the cause of "momentum"; and work, which is the energy due to the action of the force.

371. Gravitation is the only absolute natural force, and as it is constant in its operation, it generates not only a "velocity," but also "acceleration," that is to say, the moving body, retaining at each instant its acquired velocity, adds to this the growing velocity due to the force; but in dealing with the energy involved, the actual velocity at a given instant only is considered; regarded as a force in the abstract, gravity, *g*, imparts a velocity of 32·2 feet, or 981 centimetres per second. Regarded as a unit force, it generates this velocity in a mass of one gramme. See also § 431.

372. Hence we have the following units:—

			Unit value.	Name.
V,	Velocity	$L \div T$	1 centimetre per second	—
F,	Force	$L \times M \div T^2$	ditto in 1 gramme	Dyne.
W,	{Energy Work}	$L^2 \times M \div T^2$	1 dyne in 1 centimetre	Erg.

We see here the connection and the distinction between Force and Energy. *Force* is measured by the *velocity* it sets up, the *momentum* generated, therefore by length, L. *Energy* is measured by the *square of the velocity*, the vis viva, therefore by L^2. But while *unit* force and *unit* energy are the same value (one cause, the other effect, each equal to each), force and momentum increase in the ratio of *velocity* or L, while energy or vis viva increase in the ratio of the *square of velocity* or L^2, which means the arithmetical product, not the square, in the sense of "area."

373. GRAVITATION.—To understand these values it will be well to compare them with the familiar terms based on gravity. The force of gravitation (upon the earth) varies according to the distance from the centre of the "mass" of the earth; at the equator it is 978·10, at latitude 45° it is 980·61, at the poles 983·11, these being velocities in centimetres. Taking the value in England as 981, the force of gravity equals 981 dynes, or C.G.S. units of force. The actual force of gravity at any part of the earth is ascertained by the following formula: $g = 978{\cdot}1028 \times \text{cosine } 2\lambda - {\cdot}000003h$, in which λ denotes the latitude and h the height in centimetres of the place above sea-level.

374. The *erg* may, therefore, be compared with the common mechanical unit of work, the foot-pound, because the ft.-lb. is the same thing as 138·25 gramme-metres, or expressed in C.G.S. system as 13825 centigramme-metres; then, if we take gravity, g, as equal to 981 dynes in this system, we find that the ordinary ft.-lb. is equal to 13,564,325 ergs. Such a figure shows at once that this system is really adapted only to minute measurements. To get rid of the numerous figures involved, a simple system of writing is adopted, and the above figures would be written as $1{\cdot}356 \times 10^7$ or 1356×10^4, and most of the calculations involved are thus reduced to the alteration of the index figures.

375. This system is becoming so increasingly common in electrical and scientific works generally, that it may be well to explain it. The index, as in logarithms, may be *positive*, signifying the "power"—that is, the number of tens by which the figure is to be multiplied, or *negative*, signifying the number of tens by which it is to be divided; thus the negative index written with a dash represents a *decimal fraction*. Thus we have—

1×10^6	= 1,000,000,	a million
1×10^3	= 1,000	a thousand
1×10^2	= 100	a hundred
1×10^{-2}	= ·01	a hundredth
1×10^{-6}	= ·000,001	a millionth

In fact, the positive index, as in logarithms, is one less than the figures representing the number; but the negative index, unlike the logarithmic, is the number of figures representing the decimal when written out.

376. In speaking or naming these values, we are burdened with a barbarous nomenclature; thus, a million ergs is called a megerg or an erg-six, and ten million an erg-ten, and so on, adding the index number to the name of the unit. Furthermore, in electricity, we have the generally adopted prefixes of

mega, signifying a million, as the mega-volt or meg-ohm; and *micro* signifying a millionth, as the micro-farad, besides the ordinary prefixes of the metric system of measures.

377. It is a serious inconvenience that the fancifulness of the mathematicians has led them to adopt the centimetre instead of the metre as the basis of the unitary system. English men of science have gradually accustomed themselves to the metric measures and the various units based upon it, and students begin to understand what is meant by a gramme-metre as the unit of work, and the calory as the unit of heat, and now they are being puzzled afresh by a new system. But, as our writers are chiefly these mathematicians, and they are the teachers in the schools, they have it in their power to force people to submit. It would be of little consequence if (as many at first sight suppose) it only meant the adding of 100 to all values as the result of using the centimetre (or one-hundredth of metre) in place of the familiar metre itself. But this is not the case; as energy, or work, varies as the square of the force, therefore, unit force or velocity on the metre-gramme-second system means 100 times the unit force on the centimetre-gramme-second (C.G.S.) system; but unit energy is, consequently, in the metre system, 100^2, that is, 10,000-fold in value the unit energy of the C.G.S. system.

378. ELECTRICAL UNITS.—In all measurements it is necessary to have a separate starting-point or "unit" for each order of things or conceptions, though these units may be derivable from the few fundamental units—thus, from the unit *length*, 1 centimetre (or metre, or foot, as may be), we derive unit *area*, the square centimetre, &c., and from this again, unit *volume*, the cubic centimetre, &c. In like manner, each separate conception or order of facts in electricity requires to have a unit of its own, and the system is similar to that of the mechanical units which have so far engaged attention. Here, also, we start from a "force" generating a velocity. We can now replace the attraction of gravitation by two distinct attractions of electricity. We have the force exerted by an electric "charge," § 74, from which is derived an electrostatic system of units; and we have the attractions exerted by an electric "current" upon a magnetic pole, or upon another current: this furnishes the electro-magnetic system of units. The static system has been examined, § 72, and does not call for much attention here. The unit of the magnetic system is based on the unit magnetic pole, which is one which repels a similar pole, one centimetre distant, with a force of one dyne, § 134. The unit electric current is that which, in an arc of one centimetre length of a circle of one centimetre radius, will

repel a unit pole at its centre with a force of one dyne. The unit current would also, in a length of one centimetre, repel a similar current at a distance of one centimetre with a force of one dyne; that is to say, such a length forming an arc of a circle of 1 centimetre radius would produce a unit field of force, § 133, at its centre, and more generally a current C in a circular arc produces a field equal to C × length of arc ÷ square of radius, from which are derived the formulæ § 323.

Perhaps the easiest method of forming a concrete idea of these forces is to conceive a spring balance adjusted to carry a weight of $\frac{1}{981}$ of a gramme. Any force whatever which strains the spring to that point is exerting unit force. Thus, if a magnet-pole, fixed at one centimetre from another magnet-pole, required the spring to be stretched to that point to resist motion (that is, to maintain the centimetre distance) a force of one dyne would be exerted; or, what comes to the same thing, if the balance were graduated to successive increments of that value, it would indicate the number of "dynes" exerted by any force. The ultimate idea of force is *pressure* or *tension*, attraction or repulsion really in unit degrees, but for purposes of calculation expressed in relation to mass.

379. The two systems of units are related to each other in a ratio expressed in the formulæ as *v*. The actual value is not exactly known; but it is interesting for two reasons. It has been experimentally determined by several eminent electricians by different processes.

		Per Second.
Weber and Kolrausch	make it	$3 \cdot 1074 \times 10^{10}$ cm.
Sir W. Thomson	„	$2 \cdot 825 \times 10^{10}$ cm.
„ (another mode)	„	$2 \cdot 93 \times 10^{10}$ cm.
Clerk-Maxwell	„	$2 \cdot 88 \times 10^{10}$ cm.
Ayrton and Perry	„	$2 \cdot 98 \times 10^{10}$ cm.
Average		$2 \cdot 9445 \times 10^{10}$ cm.

These variations, though not large, show (like the different values found for the ohm) that while mathematicians work out their formulæ to the extremest nicety, the data are by no means settled.

The other point of interest is that this ratio, which is really a velocity, is apparently identical with the velocity of light; the various determinations of which range over much the same values as the above.

380. DIMENSIONS.—The values of the various units of the system are derived from considerations classed under the name

of "dimensions"; derivations in fact from the unit length L, mass M, and time T; which dimensions, therefore, are alike applicable to any actual values given to those units in any system.

MAGNETIC UNITS.

Strength of magnetic pole *m* $= L^{\frac{3}{2}} \quad M^{\frac{1}{2}} T^{-1}$
Moment of a magnet *m l* $= L^{\frac{5}{2}} \quad M^{\frac{1}{2}} T^{-1}$
Intensity of a magnetic field H $= L^{-\frac{1}{2}} \quad M^{\frac{1}{2}} T^{-1}$

ELECTRIC UNITS.

Units.	Electrostatic System.	Electro-magnetic System.	E. Static. E. Magnetic.
EMF	$L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}$	$L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}$	$L^{-1} T = \frac{1}{v}$
Resistance	$L^{-1} T$	$L T^{-1}$	$L^{-2} T^2 = \frac{1}{v^2}$
Current	$L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}$	$L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}$	$L T^{-1} = v$
Quantity	$L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-1}$	$M^{\frac{1}{2}} L^{\frac{1}{2}}$	$L T^{-1} = v$
Capacity	L	$L^{-1} T^2$	$L^{-1} T^2 = v^2$

381. The units thus ascertained represent each its own idea, thing, or action, as shown by the dimensions which represent their values, but the system is so related that we may actually treat them as though they were all one absolute unit, representing all forms of force and energy, cause, agency, and effect; we may multiply and divide them by each other as though they were abstract numbers merely, instead of concrete things. In the first edition, this feature of the system was so much dwelt upon, that some readers overlooked the fact of the inherent differences among the units, which has induced me to point it out more particularly now. The arithmetical unity of relation is, in fact, the great advantage of the use of an absolute unit, and it results from the fundamental principle of the system—viz. that a unit force, acting in unit time and unit mass, will produce a unit effect or operation, and expend and produce unit energy in some of its manifestations. Therefore the ratios or actual values of the units themselves are fixed by this necessity. Starting from any two, the rest follow of course, from Ohm's formula, § 423.

This relation, in fact, involves that unit current C must pass through the unit conductor (miscalled resistance, § 439) R, in unit time, under the influence of unit E M F or E; and in doing so shall expend unit energy or work, and be capable of being stored in a receiver of unit capacity, and of exerting unit force upon a unit pole or current. Hence, all being alike represented by 1, and being all inter-related, there follows the fact mentioned, that we can treat them as simple numbers without regard to their actual natures.

382. PRACTICAL ELECTRIC UNITS.—The units employed by electricians and forming the B. A. system, were selected so that they should be of a convenient magnitude, and yet be decimal multiples of the absolute units of the metre or centimetre-gramme-second absolute system and also approximate in value to units already in use.

383. The VOLT is the unit of *electromotive force*, and in the formulæ is symbolized by E; when of the nature of an opposed or *counter electromotive force*, as in the case of a reversed cell, such as a voltameter, secondary battery, &c., it is written $-e$. The volt is, therefore, the unit of all the various expressions or actions, which are either consequences or parts of electromotive force, or which are simply other names for the same thing, such as "potential," "difference of potential," "electric pressure," and "electric force."

The VOLT represents a static force or pressure; there exists no standard of it at present, but it is purely a matter of calculation. It is of the value of 10^8 C.G.S. units (10^5 M.G.S.). This value was selected as being the nearest approximation to the Daniell cell, which is the most constant known; the volt is Daniell ·9268. As the E M F developed in a thermo-electric battery is constant for a fixed range of temperature, and as the freezing and boiling points are easily producible, it is probable that a standard volt might be constructed by this means; but it would not be reproducible exactly, because any variation in the purity of metals alters the conditions; it could, however, be copied like the ohm.

384. The OHM is the unit of what the electricians call ***Resistance*** —as to the nature and true explanation of which term see § 441. It is symbolized by R when general, but when it is subdivided into the several parts of the circuit it is written r, r^1, &c. Its value is 10^9 C.G.S. units (10^7 M.G.S.), and this value was chosen because it was a near approximation to the Siemens mercury unit, which was largely in use. This unit, which is a column of mercury 1 metre long and 1 millimetre section, at the freezing-point of water, equals ·953 ohm. To give a definite idea of the ohm, it may be said to be equal to a wire of copper

of 95 per cent. conductivity, such as is ordinarily obtainable, 10 feet long, ·01 inch (or 10 mils, about 32 gauge) § 466, weighing 2 grains per foot. Any other wire, of whatever material or size, or any electric circuit which would equally divide an electric current with this wire, would be 1 ohm of resistance.

The exact value of the standard ohm prepared by the B.A. committee is not known certainly. The following list of the different experimental determinations shows both the difficulty of these exact experiments, and the real uncertainty which still exists as to the data upon which mathematicians build up elaborate calculations.

1862.	Weber	1·088
1870.	F. Kolrausch	1·0196
1873.	Lorenz	·9797
1876.	Rowland	·9912
1877.	H. F. Weber	1·0020
1881.	Lord Rayleigh	·9895

As these differences are found by most skilful experimeters, aided by the most perfect and complete appliances, it is not a matter of surprise that the actual units obtainable vary considerably from each other. An international committee is appointed to settle this matter; and it is stated that a preliminary decision has been arrived at which is so injurious to future science as to call for urgent protests. It is resolved to construct a new standard and reproducible ohm, which is to agree in value with *the existing ohm, be that correct or not.* The reason given is, that to alter the standard would make all existing instruments incorrect, while the true value of the existing standard being ascertained, it will only be necessary to use a constant for correction in calculations. It is said that the fact that the practical ohm is not exactly 10^9 C.G.S. units is of no more moment than the fact that the metre is not exactly its theoretical proportion of the earth quadrant. But the cases are in no way analogous: any unit of length may serve as the basis of a complete system. Its relation to the earth's quadrant is of no more consequence than its relation to the height of St. Paul's. But the ohm is part of a system closely related to its theoretical basis. All calculations of current, energy expended, and so on, are dependent upon this ratio. The question resolves itself into a choice of two evils:—

(1) The existing standard is changed for one theoretically true.

Evils. Existing instruments become incorrect. But as it is, they are not really correct to the existing standard; they generally alter in course of time, and any change would only need a correction of results by a constant. This evil would, therefore, wear out in time, with the existing instruments.

(2) The existing standard is retained.

Evil. For all future time no observations will be correct; every calculation will need a correction; the true relations of electric constants will always be obscured.

Can there be a doubt which is the lesser evil?

385. It is intended to make a reproducible ohm, which will be a great advantage; but the mode is open to question. The intention is to define what length of a column of pure mercury of 1 millimetre section is a true ohm. Mercury is far superior to any solid metal, because it is capable of easy purification, and is subject to no molecular changes; but how the column of mercury is to be produced is questionable, seeing that no glass tube can be drawn true; also a fractional length will be difficult of adjustment. The plan which I have suggested gets over this; let a V-groove be formed in ebonite or glass, exactly 1 metre long, or two such grooves side by side, half a metre long, and connected by massive copper at one end, so as to have the terminals side by side; this being placed exactly level, let so much mercury be put into the grooves as shall exactly make the ohm: this would make its own section, and all that would be necessary would be to ascertain exactly the weight of mercury required; weight and length, the two easiest measures to determine exactly, are all the data which would be required; a cover applied would complete the apparatus, with suitable arrangements for keeping it at the proper temperature.

386. The AMPÈRE is the unit of *Current* per second, the one thing which has an actual value in nature, which value is not, however, taken into account in the system. The unit value of current is defined of necessity by the relations of Ohm's formula—

$$\frac{\text{E}}{\text{R}} = \text{C.} \quad \frac{\text{E M F}}{\text{Resistance}} = \text{Current.} \quad \frac{\text{Volt}}{\text{Ohm}} = \text{Ampère.}$$

$$\frac{10^8}{10^9} = 10^{-1}\ \text{C.G.S.} \quad \text{or} \quad \frac{10^5}{10^7} = 10^{-2}\ \text{M.G.S.}$$

The ampère was formerly called the veber. Its actual value is not yet ascertained satisfactorily, and the difference of values given is considerable. The value accepted until recently is that employed in this work, which makes the ampère a current which, doing work in electrolysis, releases ·00001022 gramme of hydrogen per second, or in grains ·000158, and the equivalent proportion of any other substance. M. Mascart has recently given as the value, gramme ·000010415 of hydrogen, which is in grains ·000161. Until the matter is finally decided by some recognized authority, I have not thought it desirable to alter the values given in this work, which can be altered by a percentage correction if the value of Mascart is preferred.

An *ampère hour* is a larger unit coming into use for electric light purposes, and is used as a unit of quantity, being the value of 3600 coulombs, or ampères.

387. The COULOMB is the unit of *Dynamic Quantity:* it is of the value of 1 ampère of current; that is, a current of 10 ampères would transmit in one second 10 coulombs of electric quantity; the coulomb is, therefore, C.G.S. 10^{-1}, and represents chemically, grains of hydrogen ·000158, or such values as have just been described for the ampère.

388. The FARAD is the unit of *Capacity*, and its value is coulomb ÷ volt, or C.G.S. 10^{-9} units (M.G.S. 10^{-7}). That is to say, that the capacity of a condenser for charge is the number of units of quantity it will receive under unit force. The value given is that of the electro-magnetic unit system, and a unit condenser would therefore be one holding 1 coulomb under 1 volt potential. It will be seen, § 93, that the unit of capacity on the electrostatic system is a sphere of 1 centimetre radius, which would hold the quantity defined, § 72, so that on this system the capacity of the earth is calculated as 630 millions e-s units. ***But all this belongs to the electricity which has been invented by the schoolmen;*** as to the earth, there is not an iota of evidence that it has any static charge at all as a whole—i. e. as a sphere in space: it has many local charges, constantly varying, set up between parts of its surface and the surrounding atmosphere and clouds. Its capacity is imaginary, but the figure is useful to give some conception of the meaning; dividing this charge by the ratio v^2, § 379, we have $63 \times 10^7 \div (3 \times 10^{10})^2 = 7^{-13}$ C.G.S. units, and the microfarad being 10^{-15}, this is 700 microfarads, or about 2400 miles of cable, and ·1104 millionth of a grain of hydrogen as the chemical equivalency of the electricity which would charge the earth to the potential of 1 volt.

389. The MICROFARAD is the practical unit of capacity, as the farad itself is out of all practical use. This is the one-millionth of a farad and may be represented by 3·5 miles of average telegraph cable: see § 93 (*e*) p. 78, and the table p. 81, where the natural truth as to capacity is fully explained.

390. The JOULE or JOULAD (name not yet accepted) is the unit of *Energy*. It is the work expended by the ampere in 1 ohm, and

its expression is $J = C^2 \times R$. This is the energy expended, the work done in passing the current through the circuit. *It is the true resistance*, and it is analogous to mechanical friction, and, like it, varies as the *square of the current;* as the formula $E \times C$ means exactly the same thing for any given circuit (only substituting a measured E M F for a measured resistance), this formula also gives us the result in what are called volt-ampères, which are the same thing as the joule. This name has been recently proposed by Mr. Siemens, as a suitable recognition of Joule, the measurer of the actual co-relation of work and heat; but it has been in use for years (as the joulad), proposed by D. G. Fitzgerald on the same ground.

The *joulad* covers all forms of energy, and includes W work in foot-pounds or other measures, and H heat in calories, &c. Therefore it needs a constant *k* to be added to the formula, which would give the value in the desired terms. Thus the joulad means:—

C.G.S. (ergs)	$\cdot10^{7}$
M.G.S., 1000	$\cdot10^{3}$
Foot-pounds	·7373
Calory	·24065 *
Grain Degree Fahr.	6·6855

391. The WATT is suggested as the unit of *Power* (similar to horse-power); it holds much the same relation to the joulad as the coulomb does to the ampère. It is, in fact, the power to do a joulad of work, and is of the same value per second as the joulad, or equivalent to 44·25 foot-pounds per minute, or horse-power (33,000 foot-pounds per minute) ·00134; so that

1 horse-power = 746 watts;

that is to say, one horse-power expended wholly in producing electric current would generate

1 ampère current in .. 746 ohms resistance,
or, $\sqrt{746} = 27\cdot3$ ampères in 1 ohm ,,

In fact, we may consider the joule as the cost of carriage per ohm of one ampère, but with the charge increasing as the square of the number of ampères carried per ohm.

---

* Two values in calories are given, ·24065 here, and ·2381 in the table. The first is that hitherto used, and ascertained by experimental observations: the latter is the theoretical value derived from the C.G.S. system; the difference is caused by the imperfect determinations of the standard units, the ohm and ampère.

392. The *volt-ampère hour* is a larger unit of energy corresponding to the similar current unit, § 386, which is coming into use in connection with electric lighting, and represents 3600 joulads.

393. Further information as to the principles which underlie these units will be found in the chapters relating to the several branches, and the following table will present the relations of the units to each other and their values in one view.

PRACTICAL ELECTRO-MAGNETIC UNITS.

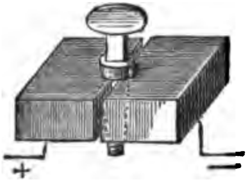
Subject.	Symbol.	Name.	How derived.	Values of Units.		
				C.G.S.	M.G.S.	Practical.
E. M. F. . .	E	Volt	Ampere × Ohm	10^8	10^5	Daniell ·9628
Resistance .	R	Ohm	Volt ÷ Ampere	10^9	10^7	Siemens' 1·026
Current . .	C	Ampere	Volt ÷ Ohm	10^{-1}	10^{-2}	Hydrogen equivat.
Quantity . .	Q	Coulomb	1 Ampere	10^{-1}	10^{-2}	Gramme ·00001022 Mascart gives
Capacity . .	K	Farad	Coulomb ÷ Volt	10^{-9}	10^{-7}	„ ·000010415
„ practical	..	Micro-farad	„ 1 millionth	10^{-15}	10^{-13}	3·5 miles of average cable.
Energy . .	J	Joulad	$C^2 \times R$	10^7	10^3	10^7 ergs.
„ as Work	W	„	$E^2 \div R$	„	„	ft. lb. ·7373
„ as Heat	H	„	$E \times C$	„	„	Calory ·2381
Power . . .	..	Watt	1 Joulad per sec.	10^7	10^3	Horse-power ·00134
„	..	Volt Ampere	W ÷ time	„	„	44·24 ft. lbs. per min.
Electrolytic Current	..	*Chemic*	Ampere = 5·68	..	..	1 grain Hydrogen in 10 hours.
Energy	..	*Equivolt*	6338 Joulads	..	..	4673 ft. lbs.

394. RESISTANCES MEASURES.—These are definite resistances made up into sets for use precisely as weights are in ordinary weighing, and by a process so similar that the apparatus is called a "Balance" in which these known measures are compared with the one to be measured until the two are equal in relation to electricity as the weights are as to gravitation. The earliest were simply lengths of a particular wire; then Wheatstone's Rheostats were devised, these being wires of which variable lengths were capable of being measured off: one form consisted of a length of fine wire wound upon two parallel cylinders geared together, the one of wood with a screw thread cut in it, the other metal, so as to make contact with the wire wound upon it, leaving the length on the wooden cylinder to form part of the circuit: the other was also a wooden cylinder with a stouter wire wound upon it, forming a

screw thread against which pressed a travelling wheel on a metal arbor. In both instruments there were appliances for indicating the number of turns and parts of a turn which were left in the circuit: but both were very imperfect because the contacts were unreliable. Then fixed coils of wire were used and mounted in sets, and from these have grown up the instruments now used containing assorted sets of coils adjusted to ohms, § 384, or any convenient multiples.

395. Resistance Coils.—These are easily made up to any resistance. They are commonly mounted up in sets, giving 1000, 10,000, or 100,000 units, and are very expensive instruments, owing to the great labour of adjustment. The usual plan is to make up coils corresponding to the required divisions and connect the several terminals to massive blocks of brass arranged nearly in contact, so that a hole bored at the middle of the opposed edges will connect the adjoining blocks when filled up by a slightly conical metal plug. Fig. 57 shows the mode of connection which is largely employed in electrical instruments, and gives an excellent connection *if kept clean*. When the plugs are inserted, the circuit passes through them and there is no resistance; by removing a plug the current has to pass through the wires whose ends are connected to the two blocks. These blocks are commonly screwed upon a plate of ebonite or wood, &c., standing above it: this has the disadvantage of allowing dust, &c., to collect; they should either be sunk into ebonite, which could be done before this is hardened, or else all the spaces should be filled up with pieces, so as to leave a smooth surface with no openings but the plug-holes.

Fig. 57.



396. To reduce the number of these connections, it is usual to make up the coils on the same principle that chemical weights are divided, viz. 1, 2, 3, 6, as by combination of these, 10, or any of its subdivisions, may be obtained; in other cases the combinations of 1, 2, 3, 4 or of 1, 2, 2, 5 are used. These combinations have the advantage of requiring only four reels and four adjustments to each decimal series; they are therefore cheaper to make in a large way; but they are more troublesome to use than instruments with complete decimal sets as described below, as they require more arrangement of the resistances, and they are more conducive to mistakes as they necessitate the adding together all the resistances opened. In these instru-

ments there is a complete wire circuit all through the instrument, and the plugs "short circuit," or shut off so much of the wire as may not be required. In the next form, on the contrary, there is no through wire, but such lengths as are required are thrown into circuit by a single connection for each decimal set.

397. Decimal Resistance Instrument.—Consideration of the various advantages and evils of these instruments, both in principle and convenience of construction by amateurs, led me to devise an arrangement, which—writing as I do expressly to aid those who wish to construct instruments for themselves—I will now describe. In giving its mode of construction I shall endeavour to furnish such practical observations as my own experience indicates may obviate difficulties likely to arise in the construction of instruments. The instrument described gives resistances varying from 1000 ohms to 1–1000, but for convenience of making and facility of reading, the elements are not distributed as just described, but in regular decimal sets of nine exactly similar parts, the terminal connections arranged as in Fig. 58, which represents one decimal set for any division. Each segment represents a connection, § 398. C, the centre connection, leads either to *o* of the next series or, in the last, to the terminal screw. A glance will now show that the current enters at + which is connected to *o*; if this is connected to C, the circuit passes from this to the next series, while if C is connected to any of the numbered studs, just so many divisions of resistance are included in the circuit.

Fig. 58.

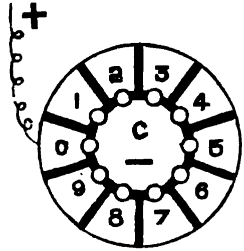


Fig. 59.

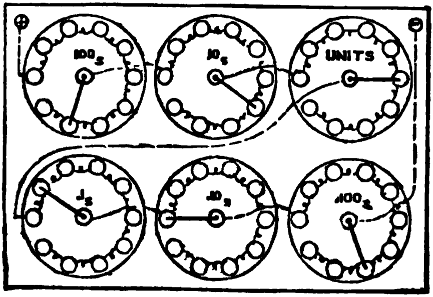


Fig. 59 will now show the complete arrangement: the upper sets represent whole numbers of units; the lower sets, the decimal divisions; all arranged in the usual mode of placing figures. The resistance as it is shown, therefore, reads off 865·107 units. The dotted lines represent the fixed connections, and the path of the current may thus be readily traced through the diagram.

398. CONSTRUCTION OF RESISTANCE INSTRUMENT.—(1) *Connections.* These may be made like Fig. 57, but composed of a circular block surrounded by a ring of segmental blocks with the necessary holes to connect each segment to the centre, as shown Fig. 58.

They may be a central pillar with a spring traversing over a ring of studs or segmental blocks; the spring should be wide enough to pass from stud to stud without break of circuit. This plan is very quick and handy in use, but is only suited to large resistances; the varying pressure of the spring, the coating of the studs with dust or smoke, makes a great difference in the contact resistances. If employed, the spring should press strongly, and all the faces be well gilt. The best plan, but troublesome in some respects, is to use mercury cups, connected together by a bridge of stout copper wire. The cups are easily made by using for the top a thick piece of wood (say 1½ inch), boring holes through, and filling the lower half of the holes with a copper rod or screw, the end of which, as also of the links, should be first well amalgamated. Brass screws will not do, as the mercury would penetrate them, and iron is objectionable, both for its resistance and as being likely to disturb neighbouring galvanometers. The ends of the screws which project through the wood should be first tinned, ready for soldering the wires to them. See also § 334.

(2) *The coils.* The wire is usually laid upon reels; these may be of cast brass with a projecting end screwed to go into the blocks, in which case one end of the wire is soldered to the reel. If mercury cups are used, and the instrument cannot be turned over, it is better to arrange short coils horizontally, instead of longer vertical ones; fix to the middle line of the lower side of the top, a vertical board from which the proper number of rods project, and slip the reels on these. From each of the copper screws of the cups bring out to the side of the top two stout wires, all arranged in order along the edge, and use these for connecting the ends of the coil wires to when mounting. The adjustment can then be made conveniently as the instrument stands, the coils being all accessible and removable. The wire, cut in lengths a little in excess of the resistance required, is doubled and laid so upon the reel; this avoids any induction in the wires, as the current is everywhere reversed, and it also prevents the coils from acting as magnets upon neighbouring

galvanometers. Another mode is to divide the length of the reel in two parts by a partition, and wind half the wire in one direction in one compartment, and then reverse the winding in the other compartment: this is less perfect than the two contiguous wires, but the wire is more easily laid, and leakage is less probable. The two ends are to be left out for connection, and in fine wires it is desirable to join a stouter wire (or a short piece of copper wire) on them, to reduce risk of breaking just outside the coils. If preferred, the middle of the wire may be within the coils, so that the two ends are outward and accessible.

It is not necessary to lay the wire on reels; it may be doubled and rolled up in small coils if preferred; this has an advantage, in that it exposes more surface, and the heat of the current can escape more freely; but is more trouble in fitting up.

(3) *The wires.* These should be German silver; it is usually silk-covered, but cotton is nearly as good. It is desirable to saturate the covering with paraffin, by baking thoroughly dry and dipping while hot into melted paraffin. This can be done either before or after laying on reels. German silver wire varies very much in resistance, according to the amount of nickel in it. Of two wires of exactly the same gauge, No. 26, 8 feet of the best balanced 11 feet 6 inches of the commoner, therefore, the suitable sizes cannot be given, but must be ascertained by the formulæ given § 472 and by aid of Table XI.

It is also quite useless to measure lengths of wire, if any accuracy is desired, because the resistance varies in each length owing to slight variations in thickness, and still more to slight changes of quality, and the finer the wire the greater this variation. Thus, in No. 18 two trials differed only a quarter inch; in No. 34 many trials gave results varying from 6·4 to 7·2 inches. It is useless also to adjust wires before winding, as the strain upon them alters their size very slightly, and so affects the resistance, and this the more if, as should be done, the softest possible wires are used.

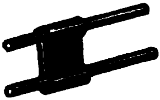
The size of wire is to be selected according to the purpose of the instrument. If it is to be used as an actual resistance for varying currents (and such an instrument is an essential) large wires must be used, to avoid the effects of heating by the current; if it is required only for measuring resistances with the bridge, as only small and momentary currents pass, fine wires may be employed. The following sizes are suitable:

Single ohms ..	No. 18.—21	100 ohms ..	No. 25.—34
10 ohms	„ 20.—29	1000 „	„ 32.—40

Decimal sets need not be all of one-sized wire; the larger sizes may be used for the first coils, and finer as the resistance rises.

(4) *Adjustment.* This is effected on the principles described § 416, by balancing against a standard. The ends of wire left for adjustment are well cleaned, and shortened by crossing in contact till closely correct, when they should be twisted together and soldered, and the twisting and soldering continued until it exactly equals the standard. The following is a more perfect plan, the result of many experiments. Having by mere contact, as before, ascertained closely the proper length, slide upon the two ends (first tinning them with the soldering iron) a short piece of brass tube, also tinned,* and press it together so as to grip the wires firmly. Slide the wire ends through this, watching the galvanometer till the resistance shows closely right, or a trifle too small; then touch the joint with a soldering iron to secure it, and allow it to cool completely. The final adjustment is to be made by lightly filing away the joint so as to lengthen the wires, or the wires themselves, so as to increase the resistance until it is correct. With fine wires it is well to join on stouter ends for this adjustment; there is also a great advantage in soldering on a second wire near the adjusting point, so that the circuit there is double: the effect is that any change of resistance involves a double change of length of wire, and also there is less risk of complete break of circuit; this may be carried further by making this second loop of much greater length than that of the wire it affects. When adjusted, the coils suspended from the top can be inserted into a case, which is to be secured by a few screws to the top, and forms the stand of the instrument. For further details of construction, see § 416.

FIG. 60.



(5) *Subdivisions of an ohm.*—These may, for ordinary purposes, be made by simple division of a length. Take 1 ohm in No. 16 German silver wire; measure carefully into 10 parts, and at each division solder a copper wire, to be taken as close up as possible to its connection. A copper or brass wire, No. 18, may be balanced against one of these tenths, and so furnish hundredths in like manner, and a length of No. 10 will give thousandths. The subdivisions may also be balanced singly by a standard ohm, using the multiplying ratios of the Wheatstone bridge.

(6) *The fixed resistance.*—The permanent connections should be made with very stout copper, the whole of the connections

---

* This tinning is best done by boiling in a tin vessel with a solution of caustic soda, adding a little oxide of tin (putty powder) and some granulated tin.

arranged for short circuit (that is from o to C), and this fixed resistance measured, and added in calculations to the resistance shown. For use with the bridge it is well to use a pair of conductors in the proper opening, and to balance against these and the fixed resistance, a length of wire which, being cut in two, is to be used to connect any resistance to the measure; then all but the actual resistance shown is neutralized, unless multiplying ratios are employed.

399. MEASURING RESISTANCES.—Electric resistances are measured by comparing them with other resistances of known amount, and the processes are of two kinds: (1) The comparing of *currents* produced against the resistances. (2) The comparing the *electric pressures or difference of potential* existing between two conductors. The first system may be applied: (1) By Ohm's laws, calculating the resistance from the known electromotive force and current. (2) By observing, with a galvanometer, the currents produced under given battery conditions; then replacing the resistances to be measured by a set of measured resistances, and altering these until the same deflection is obtained. (3) By a differential galvanometer, as described § 337. This process depends upon the laws of derived circuits, and directly balances the currents themselves against each other.

400. THE WHEATSTONE BRIDGE.—The second principle, that of comparing *potentials* purely, without any reference to the *currents* passing, is that of the Wheatstone bridge, so called because a cross circuit is produced between two points of equal potential. It is also, and more appropriately called "the balance," because that connection does as truly balance the circuits against each other as the weighing balance does the earth's attraction upon bodies on its opposite arms. It is also called "the parallelogram," because it forms a parallelogram of forces.

The principle and the use of the instrument is extremely simple; but in the books, it is made a very mysterious subject by being buried under algebraic formulæ, which make most people imagine that it is hopeless to try to understand it. The principle is that of a Rule-of-Three sum applied to the simple law of derived circuits, that the current will divide among all the branches in proportions exactly the opposite of those of their resistances, i. e. in the inverse ratio of the several resistances.

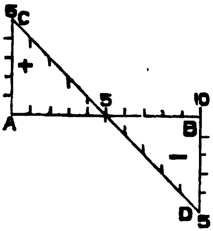
401. The distribution of potential is equally simple, if we clearly distinguish between electromotive force and potential, with their relation to current. Electromotive force is the initial or exciting cause, be it what it may: it is located at the point or points where energy takes the form of electricity. For our

present purpose we may regard it as existing at the surface of the zinc plate in the liquid of a galvanic cell, and *nowhere else*. To think of electromotive force as existing in the wires, only causes confusion. But electromotive force sets up a molecular strain throughout the whole circuit, and this constitutes the "difference of potential" between any two parts of the circuit, which is distributed (as what may be conveniently called *electric pressure*) over the circuit in exact proportion to the resistances. This conception treats potential as single, and reckons it as "above earth or zero," §§ 77 and 91. But as it is an artificial representation of the facts, it will be well to show how it properly represents the facts of the electric circuit.

402. Wherever we open our circuit, we find a positive and negative condition, a + and − pole of equal and opposite forces, these being simply the opposite faces of the particles in the circuit, §§ 35 and 108.

We should therefore begin by thinking of "electric pressure" as twofold, as representing the opposite stresses of these particles. Fig. 61 presents this view, and shows how the force is distributed. A B is the circuit (which is regarded as a resistance divided into 10 equal parts), starting from the face of the liquid A C, in contact with the zinc, and returning through the negative plate (which may be anywhere according to relative resistances) and the outer circuit to the zinc plate, B D. Treating the electromotive force as a unit, and calling its value 10, we have + and − pressures, each 5, or a *difference of potential* of 10, equal at the point of origin to the electromotive force, and drawn to the same scale as the resistance. The line C D is, therefore, the line of distribution of potential, which is likewise divided into 10 equal parts, vertical lines from which show the pressure existing in any parts of the circuit. Thus from any points on the line of potential C D, lines to the line of resistance A B will cut off a resistance equal in proportion to the sum of + and − pressures, included in the intermediate conductor, and acting to set up current in it.

FIG. 61.



It should be remembered that the actual values of the force and potential, or resistance, are of no consequence. Let them all be great or all small, or one small and the other great, these *ratios or proportions* will hold good.

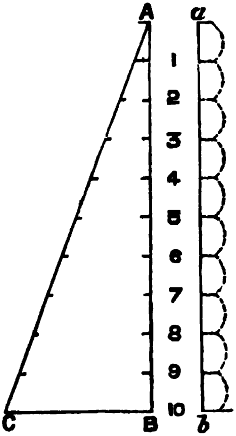
403. As yet we have regarded Fig. 61 as representing a whole circuit and force, but it applies equally to any fraction of a

circuit. Remembering the distinction made between electromotive force and potential, yet if we take any portion of a circuit, and ascertain the difference of potential existing at the two extremities of that portion, we may regard that difference as the electromotive force operating within that portion. Let A B be only a tenth part of the circuit, then if the same total electromotive force is acting, the actual difference of potential, constituting the force within this section of the circuit, will be only 1 (equal to one-tenth of the acting electromotive force) instead of 10, but its proportionate distribution over the included resistance will remain unaltered.

404. But further, these same conditions apply equally if A B, this portion of a circuit, instead of being a single path, be two or many: the total current will divide itself among the paths in the inverse ratio of their resistances, no matter how these differ, and the potential will be distributed in each of these *derived circuits* over that resistance in proportionate ratio. To show this, it is more convenient to treat the difference of potential as single, instead of a compound of + and –, especially as this gives us conditions which enable us to compare electric potential with the pressure of water.

405. Fig. 62 represents a two-branch circuit with the several pressures, but these are not, as before, on the same scale as the resistance, but merely proportional. Let us first regard the lines A B, *a b*, as vertical pipes, connected to the same reservoir of water at an elevation which produces a final pressure A B, *a b* equal in both. Now dividing the lines of height and those of pressure, each into 10 parts, or, what is the same thing, dividing A C, *a b* equally, we get lines which represent the pressure existing at each level of the pipes; but, let us now suppose that one of these pipes, instead of being vertical, goes from A to C, or that it goes to any distance away which shall lengthen its path to the level, or let it follow the dotted line between the sections; still in each proportion of length corresponding to the level of the vertical pipe A B, there will be exactly the same pressures in A B, A C, and *a b*. Therefore, at any such level or line of equal pressure we might place a cross-connecting pipe between A B

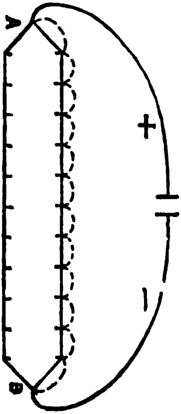
FIG. 62.



and the other pipe, and there would be no tendency for water to pass through it. But let a connection be made between, say, 2 in A B, and 5 in *a b*, and water would pass along this connection, from A towards *b*.

406. The analogy holds when we consider A B, *a b*, to be two electric circuits, branching from one conductor at A *a*, and B *b*: the potential is the same at every equal proportional part of the resistance, and at such points connections may be made, and there will be no tendency for electricity to pass across the connection, because, although there will be such a tendency at each point, it will be met by an equal but opposite tendency at the other end of the cross-connection. A galvanometer in this cross-connection will show no current passing; an electrometer would show no signs of charge. This will hold true, though the one resistance be a thousand times as great as the other; still, at the definite proportional points, equal pressures or potentials exist, and no current can pass across. Fig. 63 shows the lines of Fig. 62 arranged thus as derived circuits, forming part of a main circuit from a battery. If a connection were made between any of the opposed points no current would pass, and it would divide the circuit A B into the four arms of the bridge, Fig. 64.

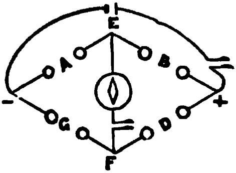
Fig. 63.



407. Construction of Bridge.—Fig. 64 explains how these principles are applied in the ordinary bridge.

The battery wires are led to the two screws from which the two branch circuits + B E A − and + D F C − start, + and − being points of equal pressure for both circuits. E and F are fixed points in either circuit connected to a galvanometer, which indicates a current passing as long as E and F are not equalized. It will show no action when the conditions of balance are fulfilled. There are thus four branches produced, and an opening is made in each for the purpose of introducing such resistances as will fulfil the conditions of balance, those conditions being that the four branches shall hold among themselves the relations of the elements of a Rule-of-Three sum: as long as

Fig. 64.



they do this the relations may be varied to suit each case. Let us call the resistance in each branch by the letter placed in its opening. Then either

1. As B is to D so is A to C.
2. As B „ A „ D „ C.

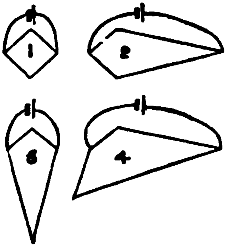
It is convenient to treat one of the openings or branches as the unknown resistance to be measured, and C will be so used. Then the law is that this resistance (C) is to the one on either side of it as the one on its other side is to the fourth. As a consequence, when there is balance, the battery and galvanometer may be exchanged in position without disturbing balance.

408. Fig. 65 shows that we have thus four arrangements at disposal:

1. Equal branches and equal circuits.
2. Unequal branches and equal circuits.
3. Equal branches and unequal circuits.
4. Unequal branches and unequal circuits.

These figures show that 1 is analogous to the ordinary weighing balance, and 2 to the ordinary steelyard. They show also by inspection which condition is the best, for throughout all nature it will be found that relations which can be expressed symmetrically are superior to those which are irregular. No. 1 is the best, and it will always be found that measurements made with all four branches alike are most accurate. Number 2 is next. These are liable only to actual errors of instruments or observations, but in 3 and 4 those errors are multiplied by whatever ratio is employed.

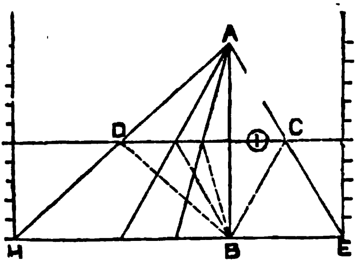
FIG. 65.



409. The whole of the principles are exhibited in Fig. 66. The line H E is the theoretical *zero of potential*, while the vertical lines are *scales of potential* corresponding to A B, Figs. 62, 63, and also mark the actual difference of potential included in the bridge, which is completed by the points D C, as shown by the dotted lines, to complete the four arms of the bridge, Fig. 66. As long, therefore, as the position of these points keeps the line D C horizontal, that is, parallel to the zero line H E, these points are equally related to the scale of potential, and no current would flow along the line D C, in which the galvanometer is inserted. But if the proper ratios are not maintained

between the arms, then one of the points D C would obviously be lower than the other, and current would flow to it. D C,

FIG. 66.



therefore, exactly resembles a balance arm in the ordinary scales for weighing.

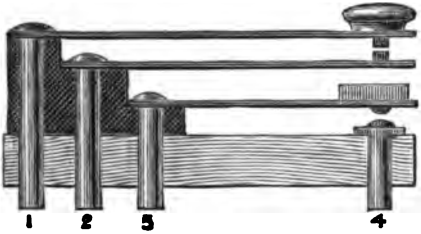
410. *The galvanometer* should be one of a resistance also approximating that to be measured, but very sensitive, the needle closely astatic and suspended by a long fibre. Of course, this element is not susceptible of much alteration, but for small resistances a good ordinary astatic galvanometer is best: for large resistances the Thomson's reflector is best suited. The law for arrangement of the galvanometer resistance is that it should equal the joint resistances on either side of it; but the best use of this law is to show with a given galvanometer what is the most sensitive arrangement of the three fixed branches. There should be, as shown, Fig. 64, a commutator in the galvanometer connection, in order to prevent the needle from being thrown about by alterations in the branches; it also enables us to make contacts in time with the rate of swing of the needle, and thus either to keep on increasing this swing, and so get a noticeable deflection, or, by opposing the vibrations, to bring the needle quickly to rest. This commutator has also the effect of allowing any inductive actions (which for the instant act as resistances) to be completed while the galvanometer is not in circuit, and so prevent its being disturbed by them. There should also be a commutator in the battery circuit, so as to allow current to pass only just when needed, and thus avoid heating the wires. For a similar reason, as well as for economy, as small battery power as possible should be used. For all small resistances, one or two cells of a good battery will suffice, but larger resistances, of course, require more, in order to set up a sufficient difference of potential in the

wires, to allow a small range of resistance to send a current through the galvanometer. As only momentary currents are needed, a good manganese cell or two will answer, but a bichromate cell, § 231, is generally useful.

411. Fig. 64 is necessary to make the principle of construction clear, but the actual instrument need not take that form at all. So long as the two circuits are properly provided, their connections may be arranged in any way. Thus a board 6 in. × 3 in. and a dozen binding screws will make a bridge; a piece of stout sheet copper, 2 in. square, cut across diagonally and holes drilled near each corner to pass binding screws through, will make the two ends; and two strips 3 in. long, each containing three binding screws, will make the middle portion of the two circuits. It is still more convenient not to set the binding screws for + and −, E and F, in their places, but to take connecting wires from those points and lead them to a pair of screws at one end for the battery, and a pair at the other end for the galvanometer. A still more perfect arrangement is to lead one of each of these pairs of wires to a commutator fixed on the stand, and from there to the binding screws.

412. The best *commutator* for this purpose is one which makes the two contacts successively with one touch, as shown in Fig. 67.

Fig. 67.

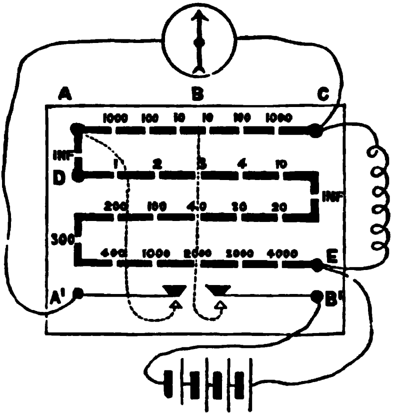


A block of ebonite or dry wood is cut with three steps, and upon each is secured a spring, having a stem passing through the block for a conductor: on the faces of the upper two springs are soldered platinum contact pieces, and also on the lower face of 3, and the top of the stud forming the fourth connection; insulating pieces of ebonite are cemented to the faces of 2 and 3; 1 and 2 form part of the circuit from one of the battery binding screws to the + or − point of the bridge, while 3 and 4 are part of the circuit from E or F to one of the galvanometer screws.

413. We have thus an excellent skeleton of the bridge, which requires the means of filling up the openings A B D to complete it: one of these is, of course, a resistance coil, § 397. For the other two openings we require two equal or proportional resistances, which may be mere lengths of wire, but should be two properly fitted resistances, variable as required. The best is a set made like the resistance instrument itself, with 1, 10, 100 ohms, and so on, which, being made all continuous, require coils, 1, 9, 90, and so on, with the power of throwing the required length into circuit. The best plan is to combine all these resistances and the bridge in one instrument.

414. Combined Bridge and Resistances.—Fig. 68 shows the ordinary post-office pattern arranged to act as a bridge. The right-hand commutator is that of the current, from which it will be seen the circuit goes to the middle of the upper line, which is the two variable resistances (as in B D, Fig. 69). The resistances from D to E are the branch A, Fig. 64, and between C and E the branch C, the resistance to be measured. The uses of the instrument are the same as that to be next described. When both Inf. plugs are in place the instrument can be used as a direct resistance throughout, between C and E.

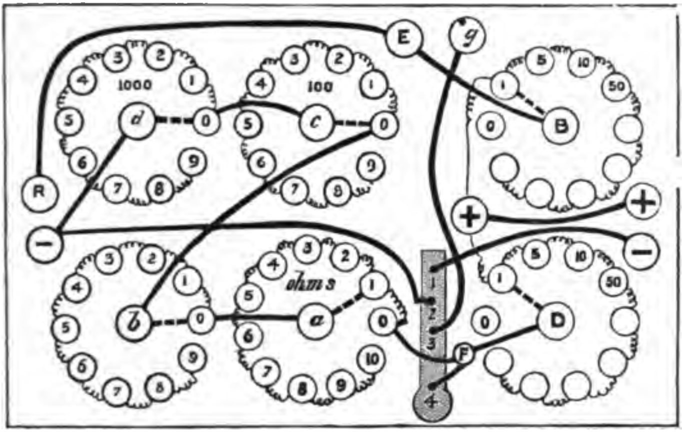
Fig. 68.



415. Decimal Combined Bridges.—Fig. 69 shows such an instrument, devised upon the principles of § 397. The lettering of the parts corresponds to that of Fig. 64, so that it is easy to

trace the connections and the manner in which they fulfil the conditions of the bridge. + and − are the binding screws for the battery wires, and their connection may be traced to + within the instrument, and through the commutator to − at the other end, these being the points at which the real bridge (the derived circuits) commences. B and D are the two variable resistances of each circuit, one of which, D, is continued through *a*, *b*, *c*, *d*, the resistance measure, ranging from 1 ohm to 10,000:

FIG. 69.



the other branch goes direct to E, and is then continued to R, which forms with − the connections for the resistance to be measured, and thus constitutes the fourth branch. The neutral points E F are connected to the galvanometer screws, one direct, the other through the commutator to *g*, which with E is the connection for the galvanometer. The instrument is shown as arranged for ordinary measurements, as though measuring a resistance of 1 ohm. By means of the multiplying ratios it would measure a million ohms or the thousandth of an ohm. It may also be employed as a direct resistance through R and −.

It might be better to divide the circles into 11 parts, so as to make each set complete without throwing any others into series. This is done with the single-ohm set, as otherwise there would always be some difficulty in making up even numbers, and there would be 1 ohm short of the 10,000. For convenience in use it would be better to place the bridge coils B D at the other end, so as to use the left hand at the commutator, while the right made the requisite changes of resistance. It would be an advantage also to make openings in the wires R E and – 2 in which coils could be inserted, adjusted to balance the connections when using multiplying ratios.

416. The *mode of construction* is identical in principle with that described § 397; but the explanation is given here how to build up the complete instrument from a single standard ohm, where the maker has not another instrument to copy. A temporary bridge, such as is described § 411, is required, and at least four exactly similar wires, as conductors for use in the openings A C. Two similar wires should be soldered to F and + within the instrument, unless mercury cups or binding screws are inserted there, as these are the starting points of the various resistances. To avoid confusion in the lettering, during the rest of this description the letters which relate to the temporary bridge will be enclosed in brackets.

Connect the battery and galvanometer to the bridge, and place the standard ohm in (A) with two long wires of near an ohm resistance, and as nearly as possible alike in (B) and (D); and in (C) a wire, which make to balance the ohm. Now change the wires in (B) and (D) one for the other; if they were exactly alike (A) and (C) should still balance; if they do not, shorten one of the wires (B D) till balance is again produced, and ascertain the exact difference of length necessary for the purpose; shorten the wire by *half* this length and readjust (C); now, if care has been taken, balance will be undisturbed when (B D) are again exchanged. In all cases this must be ensured before any reliance can be placed upon measures taken. Make in (C) two exactly similar ohm coils, which should be terminated, not with binding screws, but with No. 10 copper wire, to go into the screws of (B D), and ascertain, as before, by exchanging, that they are exactly equal, as on this will depend the accuracy of the instrument. They may be incorrect ohms if it so happens, but they *must be exactly alike.*

These being in (B D), connect the standard in (A) by two of the equal conducting wires, and by two others connect (C) to F and + in the instrument, and adjust the coil of D 1 to one ohm exact, inserting the shifting connection as shown. Then insert the connecting wires from (C) in 0 and 1 of *a*, and adjust the first ohm coil, the two ends of which are soldered to those connections. If mercury cups are used, this is done by amalgamating the ends of the conductors, and dipping them into the cups, or two of the conducting wires can have plugs on one end if plugs are used.* If other connections are used, a copper wire should be attached to each, long enough to be conveniently attached to and form part of the conductors. Repeat this with each of the ten separate ohms, adjusting them one by one.

Now disconnect the standard ohm and insert the two wires from (A) in *a* 0 – 5 and those from (C) in + and F as before, and adjust D 5. Then including *a* 0 to 10 in (A) make in (C) two approximate 10-ohm coils. Place these in (B D) of the bridge, with the same precautions as before of exchanging and equalizing them, and make a correct 10-ohm coil for use in (A) of the bridge. Using this as the standard ohm was used, go through exactly the same stages as before, and so adjust D 10, *b* 1 to 10, and D 50. When this is done, *a* and *b* together will furnish the basis for a 100-ohm coil, allowing in the connecting wires for the extra resistance of the fixed connection between *a* and *b*. Go through the same process with *c* and *d* till the whole 10,000 ohms are built up and those of D completed to such extent as is desired. The coils of B may be also adjusted at the same time, and in a similar manner with those of D, by using the E connection instead of F; but it will be much better to balance them direct by the instrument itself against those of D by connecting in turn in R – the standard, 10, 100, and 1000 ohm coils, and opening equal resistances in *a*, *b*, *c*, *d*. The fixed connections shown in thick lines are secured to the lower face of the top, and as they form the closed circuit of no (measured) resistance from F to –, they should be of the stoutest copper convenient, such as No. 10 doubled, as this resistance is a source of inaccuracy with multiplying ratios. See end of § 415. The connection between R and E is to be also of copper, and to exactly balance the other connection, by putting F – (the movable connections being all on *o* of each set) in (A) of the bridge and E R in (C), and adjusting the length of this to balance. This should be done before adjusting the coils. If all is correct, with 1 ohm in R and – and one in B, *a b c d* ought to balance the ohm, or such multiples as D is set at should be required; which last is unlikely to be exactly realized by any one not well practised in adjusting. In each of the sets, care should be taken that any little residual errors should be alternately opposite, so as to rectify each other as the resistance increases, instead of the error accumulating. While adjusting, the greatest care must be taken not to hold the wires in the hand, or to expose them to any unequal heat; and when that is necessary, as in soldering, to allow them to cool perfectly, otherwise the resistance will be wrong.

---

* In this case it will be desirable to have holes bored *in* the segmental blocks (corresponding to Fig. 51) forming the ring of connections, by which to make direct connection to each separate coil. Screws may afterwards be passed through these holes to secure the blocks to the top of the instruments.

417. In using this, or, indeed, any form of bridge, it is desirable to make it a rule to always connect the battery and galvanometer in one way, so that the deflection at once tells whether the resistance is too great or too small. When exact balance cannot be obtained, as when part of an ohm is required, observe the opposite deflections produced, with a resistance too great, and one too small: the difference between them will show how much to allow.

418. THE BRITISH ASSOCIATION BRIDGE.—This is a special form devised for adjusting units. It is provided with a length of platinum iridium wire, with a scale and a moving clamp which corresponds to the point + in the previous figures: it, in fact, by slightly moving on the wire, alters the relation of B and C, and serves the purpose of the plan described for correcting erroneous wires. As long as A and C are unequal, the clamp has to be moved to one or other side; but when they are made equal, the clamp has to occupy the middle of the scale. A full description, with drawings, is given in the 'Reports of the Committee on Electric Standards.'

There are also a great variety of forms made for different purposes, but the principle is alike in all.

419. Condensers of known capacity may be used in the branches instead of the resistances, and an electrometer in place of the galvanometer; but this plan is employed only in connection with long submarine cables.

420. *Variable resistances* are extremely useful in many operations in which either a defined current is required, or gradual changes have to be adjusted, without actual measurement. For such purposes the old rheostats, § 394, are still useful, but as in altering lengths of wire, they have the defect of causing irregular jumps: two wires can be stretched parallel to each other, with a sliding contact-piece connecting them, but this also gives irregular contacts; either of the following plans gives a very steady action.

(*a*) A strip of wood has two V V grooves cut along it, as in the suggested ohm, § 385, which contain mercury, the one pair of ends fitted with connections and a sliding bridge of copper wire joining the two grooves at any desired point.

(*b*) Two glass tubes are mounted vertically upon a stand, their lower ends containing copper rods attached to connecting screws: two straight copper wires hang in the tubes, their upper ends being solidly connected together, and fitted with a cord passing over a pulley upon a frame double the height of the tubes: the tubes being filled with mercury, the raising of the wires alters the resistance gradually.

The wires should be well varnished all over except at the ends which should be amalgamated: carbon rods can be used instead of metal wires, and a series of such pairs of tubes fitted upon a stand will give any convenient range by proper selection of size and material.

If desired, scales can be placed behind the wires, and the value of the elevations marked upon them.

This plan may even be extended to considerable resistances, by using tubes containing sulphate of copper and allowing electrolysis to occur from the wire ends; but in this case the current should be frequently reversed. A similar variable resistance can be made with a long trough of copper solution, with a plate fixed at one end, and another movable along the length.

CHAPTER VI.

CURRENT.

421. In the chapter on Measurement, §§ 380–393, will be found a sketch of the general principles of dynamic or current electricity, which are to be fully worked out under the different heads of Force, Conduction, and Current. It is better to reverse this order in examining these details, because Current deals with actual tangible facts in nature, while the others are matters of calculation. Current in Electricity, as with water, means the rate of passage of unit quantity across any section of the conductor: its most definite evidence and measure is the chemical action produced (§ 160), which will be more fully dealt with in the chapter on Electrolysis.

422. In the older works on Electricity "quantity" currents and "intensity" currents were spoken of, and even now we occasionally meet with such an unmeaning phrase as the "tension" of a current. All such ideas which give the impression of some difference of nature in currents are misleading. Current, as such, has only one quality, its rate: a given current, that is one which will produce a certain deflection in a particular galvanometer, or will deposit a certain weight of metal from a solution, is exactly the same in its nature and properties, whether it comes from a large or small cell, from a single cell, or from a thousand cells in series. But the same current may have different effects according to its *density*, that is according to its ratio to the sectional area of the conductor, or its quantity per unit of area. This influences the temperature generated in wires, and is of supreme importance in electrolysis, as mentioned several times in the chapter on Batteries. See § 285. The reason why some of the effects of Current vary as its square will be found, § 561, and the different static stresses related to currents are explained, §§ 402–406. The term *intensity of current* is explained § 367, but some writers, anxious apparently to add to the confusion of terms, have taken of late to using this already misapplied term in the same sense as "density of current" is used here.

423. **Ohm's Laws.**—These laws or formulæ are universally employed by electricians, but are not confined to electricity, for if examined they will be found to express the common fundamental mechanical laws. The relations established by Ohm's laws between electromotive force, resistance, and the current and its work, are simply the well known laws of mechanics or the relations between force, such as gravity, weight, and velocity; and the laws themselves are merely mathematical expressions. Invaluable in dealing with the modes of operation, they only delude us if we regard them as facts, and do not clearly trace out the reasons why they are valuable. The importance of these considerations will be evident if we clearly see that, in consequence of misunderstanding this, and by converting mathematical formulæ, which are nothing but mental tools (apparatus for mechanical thinking in some sense), into actual facts and theories, electricians have actually been led into great errors as to the nature of the electric constants. To show that I am not about to fight a man of straw, I quote a passage from a lecture delivered at Glasgow by that eminent practical and theoretical electrician, Dr. Siemens, on the 14th March, 1878. Speaking of the possibility of utilising natural forces, such as waterfalls at a distance, he said:—"My critics have, however, fallen into the error of overlooking the fact that half a unit resistance is the same for a circuit capable of working one lamp as it is for working 100 or 1000 lamps. *Electricity is not conducted upon the conditions appertaining to a pipe conveying a ponderable fluid*, the resistance of which increases with the square of the velocity of flow. It is, on the contrary, a matter of indifference what amount of energy is transmitted through an electric conductor; the only limit is imposed by the fact that, in transmitting electric energy, the conductor itself retains a certain amount proportional to that transmitted, which makes its appearance therein in the form of heat."* We have here two distinct statements—1st, that in electricity a resistance is the same to all currents transmitted; 2nd, the sentence italicized, that currents of electricity and currents of water depend on different laws. Most electricians then, and many of them now, would endorse those statements. I dealt with them at the time, in the pages of *The Electrician* and the *English Mechanic*, and will

---

* Sir W. Armstrong too, in his address to the Mechanical Section of the British Association, 1881, says, "In the case of a fluid current through a pipe, the resistance to the flow increases as the square of the velocity, while in the case of an electric current the resistance through a given conductor is a constant proportion of the energy transmitted. So far therefore as resistance is concerned, electricity has a great advantage over water for the transmission of power."

do so now fully, because the clearing away of errors is doing good service to science and to my readers. The first I will deal with under its proper head, "Resistance," § 440, but the direct result of the principles now to be investigated will be to prove that *water in pipes and electricity in wires are conducted upon identical conditions.* The fundamental expression of *Ohm's laws* is $\frac{E}{R} = C$, which means force (or more correctly "potential") divided by resistance defines the current, or rate of flow.

424. It follows that any two of the three elements, E, R, and C, being known, we can calculate the third thus, using the units described §§ 383–390.

Current. $E \div R = C$. Force and resistance being known.

Electromotive Force. $C \times R = E$. Current and resistance being known.

Resistance. $E \div C = R$. Thus, with any cells the force of which is known in volts, dividing this by the current in ampères, gives us the total resistance in ohms; and if the external resistance is known, by deducting this we get the internal resistance of the battery.

Energy $= C^2$, the square of current, in unit, or unaltered conductor, or $C^2 \times R$ as a general law.

It will be seen that C and R are each the reciprocal of the other multiplied by E: that is to say, that R and C limit and define each the other under any given conditions of E.

425. The usual expression of the meaning of the formula is, *Current* is *as the Force* and *inversely as the resistance.* In order to fix the mind upon the ideas I wish to develop, I give this modified definition, *Current* is *as the E M F* (which is *potential*, §§ 74 and 77) and *as the conducting capacity.* That which in the usual expression *is called resistance,* is simply the *reciprocal of the conducting capacity*, § 439.

426. According to these relations, C varies as E, but energy, as work or heat, *which are the true resistance*, varies as E^2, that is as the square of either C the current, or E the E M F in unit or any unaltered conductor, and it also varies as the so-called resistance, that is to say, it is inversely as the conducting capacity of circuits. This is precisely the ordinary law of mechanics, say in friction, where work absorbed is as the square of velocity, and directly as some other element, such as weight.

427. The very first point as to which a clear understanding is necessary, is whether these symbols E, R, and C have any realities behind them. Do they represent facts, and if so, what facts? Or are they merely mathematical expressions, simple tools of thought? If the latter, we must carefully avoid the error of

mistaking them for facts, lest, like the monster Frankenstein, they prove too much for their creators. It will be more convenient to examine this while studying Ohm's formula as a whole, than to treat each head singly in its separate chapter.

428. *Electromotive Force.*—Is the E M F which we symbolize by E, *a force*? Let us see what idea we can form of it. A force tending to set electricity in motion; or, to use a better phrase, to set up that motion which we call electricity. Here it will be seen we have two considerations presented to us: an effect, the motion produced; a cause, the force producing the motion. Of these the first, the motion, is of necessity an actual fact, though we may hold different ideas as to what is the thing. But does the *cause*—the *force*—exist, that is to say as a special force? There are actual forces having real existence, such as the various attractions of which we may take gravitation as the type: these are, so to speak, self-existent—we know not their causes. But there are other agencies which we call forces, yet which have no actual existence. They are really transformations of energy, and are forces only in the mathematical sense.

429. *Development of E M F.*—When we dissolve zinc in a battery this force makes its appearance, § 147. It is said by some to be due to the contact of the two dissimilar metals. But one thing is certain, this force can do no work unless it is maintained by an equivalent supply of energy, and, as a matter of fact easily proved, the degree of electromotive force produced is measurable in terms of the energy transformed in its generation, which is measurable by the heat set free in the chemical combination.

But if we expose the junctions of two different metals to heat, we find electromotive force set up in degrees depending (1) upon some inherent property of the metals, and (2) upon the difference of temperature produced, which means in fact the quantity of energy which can be thrown into the circuit.

Similar results are found when we examine the E M F set up by dynamo machines. It bears a definite relation to the energy expended. We find also that though electromotive force is constantly acting upon the circuit, it has no accelerating action. We therefore conclude that it has no actual existence, but is due to conversion of energy, and that it must in some way be equivalent to the energy which it expresses. The effect of the ideas about to be presented is, that E M F (or potential) is simply an expression for, a measure of the effort of energy (potential or kinetic) to take the kinetic form under any particular conditions.

430. *Any agency may be called a force* which is capable of

setting up motion, or altering the conditions of motion in a mass of matter. Thus, if we take a ball of lead and let it fall, motion is imparted to it by gravitation. We may push the same ball of lead along a table, or by muscular energy hurl it to a distance; we may strike it, as a cricket ball is put in motion, by a percussive blow; or we may, by aid of a gun, set it in motion by means of compressed air or by the explosion of gunpowder. In all these cases motion is produced, and we may call the agency in each case a "force."

431. *Mechanico-motive Force.*—We may embody all these in one expression, and say they are due to a "mechanico-motive force," the intensity of which can be measured by its capacity to produce momentum. Of course the object of this term is to obtain an exact mechanical counterpart to the electric expression, but this term, or something like it, has actually been employed in mechanics. We have then to see whether this mechanical analogue is a force, or what is its true meaning.

432. *Static and Dynamic Force.*—There are two ways of treating and measuring a "force." (1) By the *pressure* it produces. This is a static action, and it measures a force as a *degree*, not as quantity. A force so regarded is an abstract property or power: it has no relation to energy because it does no work; though it has a relation to *potential energy*, as explained § 437 (*h*). (2) By the motion it produces in matter, and this again has two aspects. 1. *Velocity*, which may be general or abstract, as in the case of the force of gravitation when expressed by the ordinary symbol g, meaning its capacity of generating a velocity of 32·2 feet per second. 2. *Momentum*, in which the force becomes concrete and *quantitative* by the introduction of unit mass of matter, and unit time. But this is no longer true *force*, it is an expression of *energy*,—of the work a force can do under unit conditions. The *dyne*, § 372, is such a force, or more truly a mathematical expression for a unit quantity of force, and it is the same value, in reality, as the *erg*, § 374, the unit of energy: they are simply expressions for the two aspects, *cause* and *effect*, force and work, which of necessity are equal.

433. *Gravitation* as a natural force therefore produces, 1, a static pressure, 2, a velocity (say 32 feet per second), 3, a momentum in a mass (say 16 foot-lbs. per second). It also produces *acceleration*, § 371: that is to say, acting continuously, its effect is accumulative. This property would be important in a treatise on mechanics, but does not necessarily enter into the electric treatment of force; its effects are included in the actual velocity and momentum generated. But it may be well to

point out that the ordinary conception of gravitation, as due to the attraction of the earth for movable bodies, is misleading, because it leaves out of sight the part played by the second body itself. The effect of this is that while we can express a spring or steam force as a pressure of so many pounds per square inch, we cannot so express gravitation per se. We shall deal with such a pressure presently as "head of water," but this is a compound expression. Besides the attraction of the earth, it includes that of the water itself, that is, its own weight (or more properly mass). Of course it is perfectly known that this attraction is really that of the two masses, earth and body; it is only the common way of thinking that I refer to, which reacts even upon science. In our utter ignorance of the real cause of gravitation, we fix our ideas upon the mere masses of matter, and satisfy ourselves with the statement that it is $\frac{M \times M^1}{D^2}$, and in that formula we bury away the agency itself, the most perfect representation we can find in nature of an omnipresent consciousness. That formula, like the identical ones for electricity, p. 54, and for magnetism, p. 109, shows that these so called quantities are nothing but the stresses or attractions exerted by forces.

434. We wind up a spring, and we know we have stored our work in it. We wind up a weight, and we know we have stored our work in it. We speak of "potential energy" in both cases, but in how different a manner do we think of the two agencies of storage: one seems real and the other mythical: the one we call energy of *stress*, molecular strain; the other we call energy of *position*. But let us conceive a powerful spiral spring attached to a rope, passing over a pulley and thence to a winch by which the spring can be strained, or wound up. We have here a tangible agent to deal with. We see the strained spring, and we know that the spring by virtue of that strain will return us our energy by doing work equivalent to that employed in generating the *molecular stress*. But we replace the spring by a mere weight which we wind up, and then we talk of energy of position. It should be clearly realized that the two conditions are identical: in winding up the weight we have in some way, wholly unknown to us, put *a stress upon the earth* and stored energy just as certainly as in the spring. We do not know how, but in some way the force of gravitation is as surely an expression of energy stored up in matter, as is the attraction exerted between two charged electric surfaces across the strained dielectric which is expressed

by the same formulæ, § 71, and in the equivalent magnetic law § 134.

The mode of storage may, however, be still *molecular stress*, as in the spring, for a raised weight always exerts a pressure. Even while hanging from a rope, in which it sets up stress, its weight is finally transferred as pressure to the mechanism which holds the rope.

435. The most convenient illustration of the mechanical effects of force, especially as connected with the study of electricity, is to be found in "hydraulics," that is to say in the currents of water produced in pipes by the force of gravitation, which force is expressed as "head of water;" that is to say, as the height of a column of water, supposed to have an unlimited supply, which is capable of producing the required effects: head of water is in fact the product of the attractions exerted between "earth" and each particle of water in the column, and therefore of the mass contained in say a column of unit area. As the unit fall due to gravity is 16·1 feet in unit time, 1 second, it is convenient to treat that column as "unit head." Hydraulics are, however, only one form of mechanics, all of which may be related to the fall, or motions due to gravity.

436. Laws of Falling Bodies.—Gravity, as an accelerating force, generates a velocity V of 32·2 feet per second, producing, therefore, an actual motion of 16·1 feet per second. For present purposes it will be convenient to use the round numbers 16 and 32. From this it is evident that a vertical pipe of one inch section, open at the bottom, and supplied from a reservoir 16 feet high, would deliver a stream of water of 16 feet per second, neglecting any effect of friction. But this would not be the proper current supplied under unit head of 16 feet, as the water is not all under the full head, and the pipe holds it back. To have the true "head of water," and its proper velocity, we must have a vertical supply so large in section as to allow the water to descend in it with very small "velocity," though it will have, of course, the full "momentum," which is transferred to and retained by the water actually issuing. If in the side of this supply pipe or reservoir we have an opening of one inch circular, the water would issue from it with a velocity of 32 feet per second (ignoring any effects due to the nature of the opening). That is, it would deliver, per second, a stream of 32 feet long and one circular inch in area, or 302 cubic inches, which is 1·08 gallon per second. We can extend this into a general view of the force, energy, and water currents due to gravity, or to any pressure which generates the

same velocities as gravity. For this purpose I have arranged the table of "Force of Gravity and Velocity," which exhibits many mechanical principles besides those to be considered now.

FORCE OF GRAVITY AND VELOCITY.

Time in Seconds.	Velocity.		Space Traversed. Energy.			VI. + 16 gives ratio to unit.	$\sqrt{\text{VII.}}$ which is $\sqrt{\text{Head}}$ in units.
	+ per second.	Total.	Acquired.	Per second.	Total.		
I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1	32	32	16	16	16	1	1
2	32	64	32 + 16	48	64	4	2
3	32	96	64 + 16	80	144	9	3
4	32	128	96 + 16	112	256	16	4
5	32	160	128 + 16	144	400	25	5
6	32	192	160 + 16	176	576	36	6
		Momentum V × mass.	Energy $\frac{V^2 \times \text{mass}}{2}$		Head of Water. Foot-pounds.	Square of time.	Force.

437. The meaning of this table is as follows:—

(*a*) *Force*, when reduced to units, means one second's action, therefore the units of force exerted are *as the times* in seconds, Col. I.

(*b*) The unit force here is one generating a velocity of 32 feet, therefore we have Col. I., times or units of force, each separately shown, Col. II., and accumulated in Col. III.

(*c*) *Momentum* is velocity × mass: taking 1 lb. as unit mass, Col. III. gives us momentum, or quantity of motion acquired.

(*d*) *Energy* is (1) mass × space fallen, so we have the increment per second 16, added to the acquired velocity in Col. IV., showing the gain per second, Col. V., and giving the total, Col VI.

(*e*) *Energy* is (2) mass × half the square of the velocity. This is often expressed as $V^2 \times \frac{1}{2}$ mass, but while correct in arithmetical result, this is a misleading statement. Half mass can have nothing to do with the result, which is due to the fact that unit energy 16 is only half of unit velocity 32.

(*f*) Hence energy is as the square of the time, $6^6 = 36 \times 16 = 576$, as shown Col. VII. × 16. Now as the time = units of force (*a*), we have the evidence that the mathematical expression of force is based upon the square root of the corresponding energy. This is an inevitable result of the equality of cause and effect, although the statement may be heretical in form, because it expresses a truth, as do many heresies, in a different form from the dogmas of the orthodox.

(*g*) But *head of water* is as the "height of the column," which is also the "space fallen." Col. VI. therefore gives us "head of water" corresponding to the spaces dealt with, and dividing this by 16, the unit head or space in feet, it gives us the various corresponding data expressed in "units," in Col. VII.

(*h*) Assuming that the area of the column is such that 1 foot in height = 1 lb. in weight, or, generally, that 1 lb. mass is falling through the height, Col. VI. gives us by (*d*) the energy, either *kinetic* or *potential*. See §§ 432 and (*o*).

(*i*) As Col. VI. is the weight of such a column (*h*), it gives us the force defined by the static pressure exerted § 432, but it shows us that this, which I have called the "abstract force," is something different from the "force" expressed in units.

(*k*) The fundamental law of hydraulics, that is of "current" in the case of water, is that *the velocities* (that is currents) *are always as the square root of the heads*. Col. VII. gives us the "heads" expressed as units of 16 feet, therefore the square roots of these give us, in Col. VIII., the relative velocity-generating power of the several heads, corresponding to successive times in seconds, or number of units of force (*a*).

(*l*) This *square root of head*, Col. VIII., is then the same thing as the number of units of force acting, Col. I., and concentrated on the one action or mass. But it does not correspond to the static pressures of Col. VI. and VII.

(*m*) But it is evident that the two definitions of "Force," § 432, must correspond: it is impossible that the mathematical formulæ, however much they may disguise the physical causes, should incorrectly represent the facts. Expressed in "dimensions," § 380,

Attraction or Force at a point } is	$\frac{L}{T^2}$	Force is ..	$\frac{ML}{T^2}$
Acceleration is also	$\frac{L}{T^2}$	Energy ..	$\frac{ML^2}{T^2}$
Velocity is	$\frac{L}{T}$	Momentum	$\frac{ML}{T}$

That is to say, the introduction of *mass* M converts the abstract ideas or powers, acceleration and attraction, into the concrete idea of a quantity of force, and velocity into momentum, while energy or vis viva is as the square of the space through which the force acts, which is precisely the same result as (*f*) above.

(*n*) When a current of water is being actually produced, that is while the attraction of the earth is converted into Dynamic Force, *the pressure in the pipe would not be that shown Cols. VI. and VII.*, but would be lowered to correspond with the definitions in (*m*).

(*o*) Therefore the vertical pressure of the head of water, though it is the abstract force (*i*), is not the mathematical unit force. It gives us the *potential energy* corresponding to this force, if we consider the area of the column to be such as makes 1 foot in height weigh 1 lb: thus we have the potential energy in foot-pounds in Col. VI., and in units of 16 foot-pounds in Col. VII.

(*p*) What then is this *Force*, which = momentum-generating power and also = $\sqrt{\text{Head}}$, and therefore of necessity = $\sqrt{\text{potential energy}}$? It is the thing described as *Mechanico-Motive Force* (431), and therefore we may symbolize it by *M* in italics, to prevent the reader from confusing it with M as used for mass in the dimension formulæ.

438. But mechanico-motive force *M* is the analogue of electromotive force E, and so also Current in Electricity is the analogue of momentum in mechanics, for unit quantity, as the coulomb, replaces unit mass, or the pound in momentum, and a current of electricity means so many coulombs per second, just as a current of water means so many pounds of water per second. Now E M F is the dynamic equivalent of potential, and therefore potential (from the present point of view, as representing *M*, Col. VIII.) is the square root of Col. VII., head in units. It is really the square root of the potential energy, and here we may find the explanation of the conflicting definitions and ideas about potential. The favourite definition of the mathematician, § 76, is that "potential" is the work spent upon a unit of electricity in bringing it from an infinite distance; this makes it *as the potential energy*, not as its square root. Then Prof. Baynes (p. 60) says that the dimensions of electrostatic potential are those of square root of force and also those of work: the table shows that, from the present point of view, *M* is the square root, both of the static pressure before action, and of the potential energy.

From the present point of view, potential (as including both *M* mechanico-motive force and E electro-motive force, represents the number of units of the artificial force of the mathematician, —force expressed as a quantity—concentrated upon the act of generating a given momentum, *in unit mass*, or what is the same thing, a given velocity in a defined or unit quantity; Col. VIII. of the table shows this, as the figures are the same as the "times" Col. I. which are as the units of "force" which have been accumulated on the unit "mass" (or quantity) passing through the spaces of Col. VI. and VII.

439. There is, however, another way of regarding this subject, which will be found in the chapter on Electromotive Force. Then electric potential will be found to express the *potential energy*, and not its square root, because the E M F in volts generated by a chemical motion will be seen to vary directly as the potential energy converted into electric energy. It is a curious result of the construction of Ohm's formulæ that the fundamental elements E C and R may be considered as related to energy either directly or as its square root, and that *both ways will be correct*; apparently inconsistent, each is true and useful. This is really the cause of much misconception, because it is never explained, though we may find here the reason that the symbol R does correctly represent both the reciprocal of conductivity, varying as C and energy expended, varying as C^2 as shown § 442.

440. *Current*, therefore, is in water as *M* and in electricity as E, which we may call "potential." Now it is evident that if a given current of water flows through a pipe of 1 inch sectional area, an equal current will flow through a second and a third such pipe, and that it makes no difference whether we use such separate pipes or unite their capacities in one pipe of 2 or 3 times the capacity. But pipes have another property besides allowing water to pass through them. They offer a resistance, a friction which absorbs energy and converts it into heat. Electric conductors have precisely the same properties, but with a difference as to the way in which energy is absorbed. In pipes this is twofold. 1, Skin, or surface friction, dependent on the nature of the pipe, varying of course *as the surface*, that is to say as the diameter, or *square root of the sectional area.* 2, Viscosity of the water itself, which necessarily varies *as the area* or mass of liquid. In electric conductors there is only a friction analogous to this latter, due to the molecular motions which constitute the current. In each case also the absorbed energy increases *as the lengths*, and as the *square of the current.* This subject will be studied in the chapter on Resistance: for present purposes it is sufficient to say that the difficulty may be got over by considering conductors, not as a whole, not as a pipe or wire of such a diameter or area, but as consisting of so many parallel unit conductors or pipes, in each of which similar actions occur, and having a unit length. In this manner we can conceive a conductor of unit *area* or section and length absorbing unit energy while unit current is passing.

This gives us a conductor of *unit capacity*, offering *unit resistance*.

It is obvious that the laws of transmission must be: 1, *Current* is as *capacity*; that is to say, *directly as area*, which is as d^2, the square of diameter. 2, Current is *inversely as* resistance. 3, Resistance (true) is as length and as the *square of the current*, or which is the same thing otherwise arrived at, as the square of *M* or E (the potential).

441. The result is that Current is *as* Force (potential) *M* or E, and *as* Capacity, which we may symbolize as A, giving us C = *M*, or E × A. This is the natural truth which is disguised under Ohm's formulæ, § 424, C = E ÷ R. Why divide instead of multiply? *In arithmetic it is indifferent whether we multiply by a figure or divide by its reciprocal.* If we therefore, for the moment, consider R as meaning the reciprocal of A (that is 1 ÷ A), it is obvious that E × A and E ÷ R are precisely the same thing. But using the reciprocal and the division process has this advantage: we have an inverse value to employ, the true Resistance, § 390, the work done in the conductor, and this is a value which the system of units expresses in the unit ohm, § 384, as the work expended in the unit conductor, which therefore, being itself an inverse value, is directly expressed by the reciprocal of the conducting capacity.

442. Therefore the symbol R conveys two distinct things: 1, The arithmetical artifice of the reciprocal of capacity; and 2, The work expended by unit current; and these two are summed up in the term "Resistance" as used by electricians. The result is that while the actual work, the true resistance, does increase as the *square of the current*, the formula works it out truly by the direct number, because the current itself increases as E. This embodies energy as the square of E, § 437 (*f*) and (*p*); therefore we have both cause and effect expressed by the square root of the energy related to them.

443. Here then we have the explanation of the common statement that electric resistance is equal for all currents, that is to say, an ohm is 1 ohm resistance for 1 ampère or 20. This the first statement quoted, § 423, applies to the arithmetical value, the reciprocal; *for a unit conductor, pipe or wire, has the same capacity for all currents*; that is, it will permit 1 unit current to pass under 1 unit force or 20 under 20 units, § 440. But none the less it will, *for both water and electricity*, retain in Mr. Siemens' words "a certain amount of energy proportional to that transmitted:" and that is, *for electricity exactly as for water*, in the ratio of the "square of the velocity of flow."

I have dwelt so fully on this subject because I have found that it is a great difficulty to most people, and because all electrical books dwell upon the artificial formulæ, and never explain the natural truth which underlies them, and which in consequence they replace. There may seem to be some difference between the statements here and those in §§ 76–78 and §§ 367–381. This is due to the fact that while these later ideas are simple developments of the former, yet the connection between the conceptions of force and potential set forth §§ 435–437 was only perceived after the earlier parts were printed, and therefore it was necessary to go over the same ground again to some extent in this chapter.

444. HYDRAULIC ANALOGY OF CURRENT.—As stated § 440, it is difficult to present water pipes so as to perfectly correspond with electric wires. It is also impossible to work out water currents by a formula corresponding to Ohm's, when treating them as derived from head of water, or as familiar to us in the network of water supply pipes. In this case the water itself runs away, but the electricity does not, and carries energy with it, while with electricity the energy is wholly *in the circuit*. Consequently in water-works the force has to have two expressions, one for the work done in the pipes, and the other for the issuing velocity which has no analogue in electricity. But there exists a much closer analogy in the case of a hydraulic system for doing work, such as actuating the cranes in a dockyard. Here we have a closed circuit in which the water circulates, closely resembling the electric circuit, in which the engine and pump correspond to a galvanic battery. Fig. 70 illustrates this analogy.

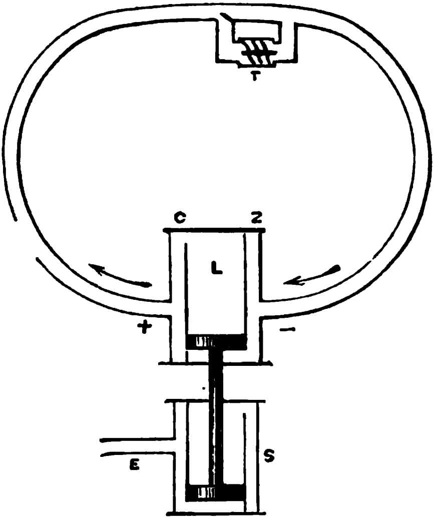
L is the pump actuated by the steam cylinder S; C being the outlet, and Z the inlet; these are connected by a continuous pipe provided with the means of connecting T, a turbine or cylinder, which may be made to do work by the pressure developed at the pump.

L is also the galvanic cell, of which C and Z are the plates, and the pipe becomes a wire transmitting the current from + to −, or in the same directions as the arrows marking the flow of water. T is an electro-magnet, or decomposition cell, or any apparatus in which work is to be done.

To carry out the analogy we must conceive E to be a steam pipe, conveying steam of, say, 10 lbs. pressure, at such a rate as to fill the cylinder, and, therefore, work the pump sixty strokes per minute when T is disconnected.

E now exactly represents the electromotive force of the cell; each filling of the steam cylinder, one equivalent of chemical action on the zinc; each filling of L, one equivalent of mechanical or electrical action. The two ideas are now exactly parallel; for each stroke of the mechanical action, fast or slow, a fixed *quantity*, or current of water flows through the pipe, and the same quantity will pass, in the same time, across every section of the circuit; so for each unit of Z dissolved, a current equivalent to one unit will flow through the wire, whether the zinc be dissolved quickly or slowly, and there is exactly the same "current" or quantity in given time at every section of the circuit.

FIG. 70.



Now let T be placed in the circuit and made to do work. This is increased resistance. The strokes of the pump—the consumption of zinc—therefore, the *current* in either case will diminish. Exactly the same laws, precisely the same formulæ, will govern the rate of decrease, mechanical or electrical.

When a certain point of diminution is attained—i.e. a certain resistance interposed at T—the pump or battery will be overpowered, and to do work we must increase the electromotive force or the steam pressure.

In both cases we see the current is uniform at every part of the circuit, and also it would be exactly equal in measure, estimated by gallons of water, and by galvanometer degrees, whether 60 strokes per minute were made by 10 lbs. steam, or one equivalent of action effected against small resistance—i.e. on short circuit, or whether T was doing work so great as to require 100 lbs. steam pressure—or 10 cells of the battery to maintain the rate of current flow.

But would the mechanical or electrical conditions be all the same? would the two currents—equal in quantity—be alike in all their properties? Most certainly not.

If we applied pressure gauges to the pipe on the + side, we should find a *pressure* diminishing as we reached the middle; on the − side we should find a *vacuum*, or − pressure, and we should find the sum of those two, at equal distances from the pump, would represent the mechanical force available between them, which would be equal also to the friction or other resistance in the intervening space. Thus, two pressure gauges, at the inlet and outlet of T, would vary according to the amount of work T was doing, and when this was so great as to need 100 lbs. steam to maintain the 60 strokes per minute, a gauge at + outlet would show ten times the pressure it would when 10 lbs. sufficed, though exactly the same "quantity" of water passed in both cases.

Difference of pressure, then, or sum of + and −, pressure and vacuum, is the measure of work in the hydraulic current, or resistance intervening. It is exactly the same with the galvanic current: mechanical pressure and electric potential correspond, as shown §§ 405–409, while the electrometer replaces the pressure gauge and measures the electric potential, p. 56, as the gauge does the mechanical potential corresponding to pressure § 435 (*n*).

445. Units of Current.—The *ampère* is described § 386. It is not yet known with certainty what is the true value chemically of the ampère and coulomb, § 387. Weber's early determination was ·0000976 of a gramme of water decomposed; later on the recognized value became ·000092, upon which are based the values used in this work; recently Mascart has revalued it at ·00009373; but Lord Rayleigh says that the appearance of accuracy in his process is delusive, so that it does not seem worth while to alter the accepted value till the matter is fully decided. This gives the value of the coulomb, and therefore of 1 ampère, as gramme of hydrogen ·00001022, from which it can be calculated for any other substance by multiplying by the equivalent of the substance, or the value in grains can be used, ·000158. The table, p. 319, gives full particulars.

The *chemic* used in these pages, § 159, represents 1 grain weight of hydrogen in 10 hours, and therefore an ampère current is equal to a current of 5·68 chemics. The reasons for using this special unit are given § 366. It can be employed with the usual formulæ of Ohm, by multiplying the EMF in volts by 5·68, when with a Daniell cell E would be called 6·1287 instead of 1·079.

CHAPTER VII.

CONDUCTIVITY AND RESISTANCE.

446. These terms are the converse of each other, but there is this important difference—*Resistance* is absolute and measurable in standard or other definite units. *Conductivity* is only relative or abstract; though it is usually stated as relative to copper as a standard, still this is only relative, as it fixes no dimensions. Conductivity can be ascertained only by ascertaining the actual resistance in a given case; then by calculating what would be the resistance of pure copper in like conditions, we obtain the relative conductivity of the substance examined. Conductivity must not be confused with *conducting capacity*, §§ 440, 441, which is the power of a definite circuit to transmit current.

Specific Conductivity.—Under the same conditions of dimension, different substances have different capacities for transmitting current; that is to say, different molecules differ in their relation to electricity as they do to heat. This relation is most easily measured as a "resistance" of a fixed dimension: a unit of dimension, now much employed in connection with the C G S system, is 1 cubic centimetre, used as in Col. III. of the Table of Resistances, p. 283, where "specific resistance" is given in the C G S units of resistance per cubic centimetre of the substance. This is useful with liquids and insulators whose resistance is large, but as relates to metals and to those using only the ohm unit it conveys little meaning, and the familiar form of a wire is that which best conveys the facts to the mind. A wire either of definite dimensions, such as 1 foot length, ·001 of inch diameter (conveniently called a *mil*, which must not be confused with the millimetre), is a very practical unit, while for some purposes a wire 1 foot in length and weighing 1 grain has its uses. These units will be employed here, and Table IX., p. 283, derived chiefly from the labours of Mathiessen, gives the most important particulars employed by electricians. Col. IV. is the specific conductivity referred to silver as 100.

447. *Alloys* usually have a higher resistance than that of the mean of their components, which appears to indicate that an

actual chemical combination has occurred, not a mere mixture of the metals. This property even affords a means of classifying alloys as of these two orders. Thus the alloys of tin and lead differ slightly from the mean, while that of tin and antimony has only $\frac{1}{30}$th of the mean conductivity, indicating a much closer combination. Other physical properties attend this classification. I have even found that the specific resistance of a wire affords an approximate test of its constitution. Thus the resistance of German silver wire, reduced to the foot-grain, varies from 2·60 ohms to 4·09, according to the proportion of nickel it contains, that of pure copper being ·219 only.

Alloys are also affected by heat, as to their conductivity, differently from pure metals, which it will be seen renders some of them very useful. Particulars are given in Table IX., below the pure metals, of a few of the most useful alloys. As a consequence, ordinary commercial metals (which are always alloyed with foreign matters) have a higher resistance than pure metals, a fact of great importance as regards copper, § 479.

448. HARDNESS generally increases the resistance of metals; this shows that transmission of electricity depends upon molecular condition, for hardness is a state of stronger cohesion and rigidity, and therefore of less freedom of motion. Annealing diminishes this strain, and allows a readier motion of the molecules among themselves, and this also allows electricity to pass more freely. This is shown in the table. As time and the passage of electric current produce a softening effect, it is important to use soft wires in instruments whose resistance is to be constant, and wherever it is required to be low, as in galvanometers. Soft wire is also much more easily arranged.

Mechanical stresses, such as torsion or tension, modify conductivity, as also does magnetism in the case of iron or steel.

449. HEAT AND CONDUCTIVITY.—As a rule, the conductivity of metals varies in the same manner for both forces—a very strong indication that the modes of transmission are similar, and that the forces are of similar nature, each a specific molecular motion.

Variation of temperature has a remarkable influence on the conductivity of bodies. As a rule, the resistance of liquids diminishes as the temperature rises, while that of metals increases. Table IX. shows that the influence on pure metals is nearly uniform, not as regards their actual, but their relative resistance. Thus, whether a metal have a high or low specific resistance, that resistance increases in almost exactly the same ratio—for instance, bismuth and copper (Column V.)—and it is very probable that slight differences shown are really due to some impurity in the metals, which are not readily obtained in perfect purity.

Mercury, however, is an exception, owing to its liquid condition, no doubt; and its slight variation is an additional element of advantage in treating it as a standard for units.

But *alloys* differ from pure metals in being much less affected by change of temperature, which, together with their greater resistance, renders them suitable for measures.

Carbon or Graphite is lowered in resistance by heat, so that in incandescent lamps a larger current passes as they become heated.

As the current itself heats the wire, the resistance varies from this cause just as though the heat were external; and it is important, therefore, in measuring resistances to use a low power. The mode of correction for the effect of temperature is given in § 464.

450. LIGHT AND CONDUCTIVITY.—*Selenium* in its ordinary state has very little conductivity, in fact copper has 38 million times its capacity; but when kept just under fusing point (220° C.) for some hours, and very slowly cooled, it assumes a crystalline condition, in which not only is its resistance greatly lowered, but becomes very variable under the influence of light. In some cases it is fifteen times greater in the dark than in sunlight. This variation is also so rapid that it produces sound in a telephone under the influence of an intermittent ray of light. Many other substances undergo similar changes, but this subject will be dealt with in another chapter.

451. RESISTANCE.—It was explained in § 442 that this term includes two distinct conceptions: (1) the arithmetical expression—the reciprocal of the conducting capacity; (2) the energy expended by the current. It is of great importance to keep this distinction clearly in view, for the law of sectional area or diameter of a conductor is related only to the first conception, while most of the other facts of resistance relate to energy expended. The clearest conception of the whole subject will be attained by fixing the ideas upon the single molecular chain, transmitting a unit electric current, as shown Fig. 43, p. 122. This shows at once that *conducting capacity* must vary as the sectional area, simply because for the same material, the quantity of the substance in the conductor, i. e. the number of *molecular chains*, varies exactly as this area. It shows that *resistance*, i. e. the true resistance, the energy consumed in the act of transmission, should be *inversely as the sectional area*, because the rapidity of the molecular motions must vary in consequence, and must vary *directly as the length*, because the number of links

in the chain, i.e. the number of molecular motions involving work, varies in that ratio. These ideas are readily transferred to the actual form of metallic wires, as in § 465.

452. Laws of Resistance.—Hence we have these laws. Resistance varies:

(1) Inversely as the *sectional area*, therefore inversely as the square of the diameter, d^2, or the weight of a given length.

(2) Directly as *the length*, the length of a given weight, or inversely as weight of a given length.

453. *Resistance* is often said to be *a velocity*. The statement conveys little or no idea to most minds, and in fact in this form it has no real meaning; it is a part of the artificial system of mathematical electricity. According to the system of "dimensions" (§ 380), resistance is expressed by $L^{-1} T$ in static units, or LT^{-1} in the electro-magnetic, and these represent velocities. There is, however, a physical fact connected to this. A current is set up in a conductor when this is made to cross the lines of force of a magnetic field. This is in fact the mode by which the value of the ohm was determined. A coil of wire of known dimensions was rotated on an axis, so as to cut the magnetic lines of the earth, and the value of the ohm is calculated from the dimensions of the coil, the intensity of the earth's magnetism at the time and place, and the velocity of rotation of the coil. Now the law of the generation of current under these circumstances is that the current depends on the number of lines of force cut, i.e. on the velocity of the conductor in a uniform field. Now we must imagine a field of unit intensity (§ 133) and a conductor of unit capacity, i.e. one which under unit E M F permits unit current to pass. To develop that current this conductor must be moved across the field with a definite velocity, and this is the velocity which is said to represent the resistance. What it really represents is the energy expended in order to generate the E M F necessary to maintain the current: it is the work done against the magnetic force, therefore it corresponds, not to the mathematical resistance, equal for all currents, but to that which I have called the *true resistance*, varying as the square of the current, § 443. The relations of the unit system are such that the velocity necessary to develop 1 volt E M F, and maintain 1 ampère current in a 1 ohm conductor, would be 1 earth quadrant, or 10^9 centimetres per second. This way of looking at the subject shows once more how the two distinct conceptions are included in the term Resistance, and both measurable by the ohm.

454. Resistance and Work.—The expenditure of energy has

thus far been considered as occurring *within the conductor*, appearing there as heat, and as an inevitable accompaniment of the transmission of current. But any work done by the current *externally*, acts also as a resistance. If an electro-magnet be excited by a battery, a current will pass according to the laws of Ohm, proportioned to the E M F and to the measured resistance, and the expenditure of energy will be measured by $C^2 \times R$. Now give the magnet "work" to do, as in holding up a weight.

(1) The current will be reduced.

(2) The expenditure of energy will be greater than $C^2 \times R$ would show.

This *external work* acts as a resistance, and an addition must be made to the measured R of the wire sufficient to account for the reduction of current: then $C^2 \times (R + r)$ would give the expenditure. Such added work may also often be treated as a counter-electromotive force. Its value in R may be ascertained by measuring the current and difference of potential between any two parts of the circuit which include the work: then while $E \times C \times J$ gives the energy expended, $E \div C$ gives the total R of this portion of the circuit, and by deducting the measured R of the wire itself, gives the resistance equivalent of the work. In like manner it may be calculated as a $-e$: if R is unchanged E is as C, therefore the difference of C in ampères, due to the work, $= -e$ in volts.

A *counter-electromotive force* may often be measured as a resistance in the bridge or differential galvanometer, and balanced by a length of wire or measured resistance; but this measure *will not be constant for all currents* as an ordinary resistance is.

455. *Inductive actions* exert such a counter E M F: such are,—

(1) *Static induction*, in one direction as the current commences to move, and in the other when it stops, but producing no effect while the current is actually passing. See § 95.

(2) *Magnetic induction*, by which the magnetic state and force is set up in matter, and energy absorbed in doing so, which as in the other case is given up when the current ceases. This also is only a temporary action, as no energy is expended in maintaining the magnetic state unchanged, unless work is put upon the magnet, § 453.

456. The resistance of a circuit expressed in the formulæ by R, is really a very complex value, varying often from moment to moment, varying by changes of temperature, &c., brought about by the current itself, and the following experiment will illustrate some of the foregoing points.

I divided one ohm of No. 20 wire (about 83 ft.) into four equal parts, and wound them on two coils, two wires side by side in each, making 97 turns for each wire, the coils being $2\frac{1}{2}$ in. long on a core of half an inch. These were intended for experiments in electro-magnetism, but they furnish the means of balancing two circuits on the Wheatstone bridge, and testing the resistances under various conditions, by eliminating every action but the one to be examined—

(1) Both pairs of wires joined in the middle, so that the current returns on itself and prevents induction; the two exactly balanced.

(2) Both coils with the current going through; exactly balanced.

(3) The coils arranged one in each way, so that there is induction in one and not in the other. Now energy is absorbed, for a current is generated at making and breaking contact, and a spark produced. This "extra" current is either created out of nothing, or it is derived from the battery: if the latter it is extra work, the resistance must increase, and show on the balance, § 453. It does so, the needle swinging 5° to one side for a moment, returning to zero as soon as the inductive action is completed, § 455, and swinging 3° the other way when circuit is broken, and the extra current passes.

(4) Both coils being arranged as in (2), they balance. Insert a piece of iron in one: the magnetizing this absorbs energy, and the needle swings 12° towards whichever coil contains the iron.

(5) I give the magnet work by suspending a piece of iron to it: the needle flies over 5° and remains there.

The facts are of course well known, but the form of this set of experiments sets them plainly forth, and brings out the relation of work to electric resistance.

457. An interesting experiment by Favre gives the quantitative relations very clearly. Testing the heat developed in varying circumstances, he found that the heat developed in a whole circuit, doing no work, was exactly the same as that given by the same weight of zinc dissolved without producing any current. Following this out, he tested the heat in various conditions of circuit, and also when a known amount of work was done by a magnet, the work being the equivalent of 308 heat units or calories.

The conditions were, for the same weight of zinc—

(1) The battery on short circuit; heat all developed in the battery itself.

(2) The circuit going through an electro-magnetic coil without the iron, as in my experiment 3.

(3) The same with the iron inserted.

(4) The magnet revolving a machine, but doing no work.
(5) The same, but doing work.

Expt.	Heat in Battery.	Heat in Circuit.	Heat lost as work.	Total Amounts.
1.	18682	—	—	18682
2.	18674	—	—	18674
3.	16444	2219	—	18667
4.	13888	4769	—	18657
5.	15427	2947	308	18682

The experiment shows very clearly the relations of energy to the effect produced, and also the mode in which resistance converts the energy into work, and it closely agrees with my experiment.

458. CONSECUTIVE RESISTANCES.—Each portion of the circuit, i. e. the various cells of a battery, the connecting wires, any instruments used or work done, having each their separate resistances measured or known, these are added together to form the total resistance of the circuit, symbolized as R. It is only this total which can be directly calculated by Ohm's formula, but the various external resistances may be ascertained by that formula, by observing the variation of the current produced as each is added to the circuit. For the internal resistance of batteries, see § 462.

459. DERIVED CIRCUITS, see § 404.—When the current divides into two or more branches for a part of its course, the joint resistance of the united circuit is ascertained by the following formulæ, the separate resistances being first ascertained by the usual processes:—

(1) $\frac{A \times B}{A + B} = R$. The joint resistance is the product of the two resistances divided by their sum. Thus

$$\frac{\cdot 39 \times \cdot 64}{\cdot 39 + \cdot 64} = \frac{\cdot 2496}{1 \cdot 03} = \cdot 242.$$

When there are more than two paths, having obtained the joint resistance of two, this is used with another in the same manner. Let C be another such path having a resistance 1·9, then

$$\frac{\cdot 242 \times 1 \cdot 9}{\cdot 242 + 1 \cdot 9} = \frac{\cdot 4598}{2 \cdot 142} = \cdot 215.$$

(2) It is more easy to obtain the joint resistance by means of

a table of reciprocals, the sum of the reciprocals of the separate resistances being the reciprocal of the joint resistance. (The reciprocal of a number is 1 divided by it; tables of reciprocals are given in many books.)

A = ·39	reciprocal	2·564
B = ·64	„	1·562
C = 1·9	„	0·526
Joint resistance		4·652 = ·214.

(3) Another plan may be derived from the system of wire resistance, § 468. If we reduce each resistance to the terms of the area of a copper wire of 1, 10, or more feet, the sum of these areas represents a wire equivalent to the joint resistance.

460. SHUNTS.—These are derived circuits, § 458, and the term is of course derived from the railway process of *shunting* a train on to a second set of rails. It is very useful to have at hand such secondary circuits prepared to correspond with instruments they may be required to be used with. Of course any wire led across connections acts as a shunt for just such part of the current as equals the ratio of the resistance, and therefore a second resistance instrument serves the purpose; but it is more convenient to prepare a special wire, equal to the known resistance of the galvanometer or other instruments it is to be used with, and coil it up with its ends left just long enough for convenient use, and label it with the purpose it is made for.

For other occasions, shunts are required bearing a known ratio, ½, 1-10th, 1-100th, &c., of the circuit they are to be used with. The following formula gives the proportionate resistance in such cases. R is the resistance of the instrument whose indications we desire to multiply, n the multiplying ratio, and S the resistance to be given to the shunt:—

$$S = \frac{R}{n - 1} \text{ ex. } \frac{53}{100 - 1} = .5353$$

Of course the addition of a shunt to any portion of a circuit lowers the resistance, and therefore alters the conditions of the whole circuit and increases the current, unless an extra resistance is inserted somewhere else to compensate for the action of the shunt, just as the insertion of a galvanometer to measure a current lowers the current previously passing.

Shunts should be made of the same material as the circuit they are used with, so as not to have their ratios disturbed by external temperature, § 449.

It is impossible to avoid the effects of self-heating by the current: in order to have the same action in both circuits the wire of the shunt ought to increase in weight in the same ratio as the current it carries; but for obvious reasons of economy and convenience this cannot be done. In fact the reverse is nearly always the case, a thinner and shorter wire being used instead of a thicker and longer. Therefore no shunts supplied with galvanometers can be relied on if more than momentary currents are passed through them.

461. *Cells of a Battery* are derived circuits to each other when they are coupled in parallel order or multiple arc, § 298, and they divide the current between them upon the same principles as explained § 458.

Cells to be coupled in multiple arc may be of various sizes, but must be all of the same kind and of equal electromotive force, otherwise the stronger cells reverse the current of the weaker, and less current passes to the external circuit than if the weaker cell were not used, and yet the stronger cell is more rapidly exhausted. Zinc may also be deposited on the negative plate of the weaker cell, if it is a single liquid cell. So also when a number of cells are arranged in sets in series, and then coupled in multiple arc, all of the sets in one coupling must contain the same number of cells, in order that when in multiple arc each branch may have the same electromotive force. In this manner a variety of cells of different sizes and forces may yet all be used in one circuit, and combined in both ways for small resistance (multiple arc) and high electromotive force (in series).

462. *Internal Resistance of Cells.*—This is subject to precisely the same laws as that of wires, § 452, but depends on the specific conductivity of the liquids contained, and varies therefore during work, as the acids become converted into metallic salts, &c.

MEASUREMENT OF INTERNAL RESISTANCE OF BATTERIES.

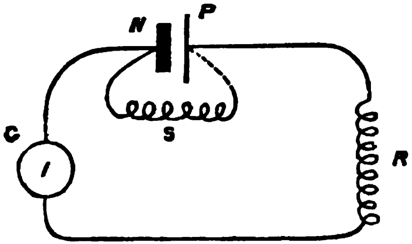
(1) *By Ohm's Formula.*—This may be ascertained by Ohm's formula when the electromotive force and current are known, for $\frac{E}{C} = R$. This is the total resistance, and deducting the external gives us the internal.

(2) *By Sine or Tangent Galvanometer.*—By means of any known resistance produce a deflection; add further resistance until a deflection is produced whose value in current is exactly half that of the first. As the current is halved, it is clear the resistance has been doubled—i. e. the second extra resistance is

exactly the same as the total of the first; therefore it is only necessary to deduct the known, or external resistance of the first deflection from that of the second: the residue is the internal resistance of the battery, together with that of any connecting wires not included in the first external resistance.

(3) *By a Shunt.*—This process, devised by Mr. Desmond Fitzgerald, is by far the simplest. Prepare a shunt or connecting wire, the resistance of which is exactly the same as the sum of all the other external resistances—viz. the galvanometer, which may be of any kind, and all the connections (and if any work is doing, the resistance of that also). Fig. 71 will now make all plain.

FIG. 71.



First connect as shown, so that the current from the battery N P divides itself through the two equal resistances, (1) S, the shunt, (2) G, the galvanometer, and R, the resistance instrument. Note the deflection carefully and then disconnect the shunt S; the whole current now passes through the other circuit, and therefore the deflection at G increases. It will be seen that in this second condition the *external* resistance is doubled, because, by the laws of derived circuits, the resistance of two equal circuits together is just half that of either of them alone, but the *internal* resistance of N P remains unchanged.

Increased resistance is now added at R till exactly the same deflection as at first is produced in G. This extra resistance is exactly equal to the internal resistance of N P, because its addition brings the current to its original amount by doubling the internal resistance, as the removal of the shunt previously doubled the external.

Methods 2 and 3 have the disadvantage that with many forms of battery the E M F varies with the rate of current, so that the conditions are different at the time of the two measures.

(4) *Mance's method* avoids this, and enables the resistance

corresponding to any rate or density of current to be measured. It is a modification of the Wheatstone bridge, and will be understood by a reference to Fig. 64, p. 246. Insert the battery to be measured in C and a resistance measure in A as usual: no external battery is used, but a contact break replaces it. If the double break, Fig. 67, is on the bridge, spring 3 should be fixed down upon stud 4 to keep the galvanometer circuit closed, and the ordinary battery connections, as + – Fig. 69 connected with a wire, when the upper pair of springs will act as the required break. It will be seen that the current from the battery in C, Fig. 64, has now two circuits from F, one through the galvanometer and the other through D B, both uniting at E and returning to C through A. If A × D = B × C, the closing of the external contact will make no change in the reading on the galvanometer, through which, in the use of the bridge, current is always passing.

The resistance of a galvanometer can be measured in this way by its own reading, if placed in C, and the battery as usual in the external circuit. This is of course the usual form of using the bridge, but requires no galvanometer in E F. The result is obtained when closing the break in E F makes no change of the reading in the galvanometer in C, which is the resistance to be measured.

There are several other processes, but they require formulæ and calculations, and I have selected the foregoing modes of measuring the resistance of batteries as the simplest in principle, most readily performed, and accurate in results.

463. *Resistance of Metals.*—Table IX. gives the values derived from Mathiessen's measures taken in connection with the preparation of the original ohm. Later determinations differ, and a set by Benoit may be found, p. 112, Vol. IV. of the 'Journal of the Society of Telegraphic Engineers;' but Mathiessen's values are generally received, and his well-known care and the means at his disposal justify the retention of his values.

Different figures are given in various books, and the specific gravity and specific resistances are by no means too certainly known; but as it appears absurd to present a set of values in one table which cannot be made to agree, with the result that the student has no definite starting-point, I have calculated the whole of this table from the two values of Cols. VI. and VII. by means of the formulæ § 473. Therefore should any other values be deemed more accurate, there will be no difficulty in altering the whole range of values, which are physically dependent on each other.

Col. III. is the *specific resistance,* § 446, that of 1 cubic centimetre expressed in microhms. By shifting the decimal point 6 places to the left it becomes ohms, and by shifting it 3 places to the right it becomes C G S units: thus copper = 1·652 microhms, ·000001652 ohms, and 1652· C G S units. Microhms are convenient for metals, ohms for liquids, and megohms for dielectrics.

TABLE IX.—CONDUCTIVITY AND RESISTANCE OF METALS.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	Specific		Conductivity silver = 100.		Resistance at 32° Fahr. of 1 ft. of wire		Variation per cent. 1° Fahr.
Metals Pure.	Gravity $= s$.	Resistance. Microhms $= R$	Weight.	Section.	weighing 1 grain. $= U$	of 1 mil diameter. $= u$	
Aluminum ..	2·574	2·944	204·05	51·67	·1085	17·72	..
Antimony ..	6·725	35·907	6·41	4·24	3·456	216·00	·216
Bismuth	9·817	132·658	1·19	1·15	18·64	798·	·196
Copper, hard ..	8·905	1·652	105·13	92·06	·2106	9·940	..
„ soft ..	8·927	1·616	107·27	94·17	·2064	9·718	·215
Gold, soft	19·639	2·081	37·853	73·09	·5849	12·52	·202
Iron, soft	7·781	9·825	20·18	15·63	1·097	59·10	..
Lead, pressed ..	11·392	19·847	6·84	7·65	3·236	119·39	·215
Mercury	13·598	96·185	1·18	1·58	18·720	578·60	·040
Nickel	8·513	12·579	14·42	12·08	1·535	75·78	..
Platinum, soft ..	21·437	9·158	7·88	16·56	2·810	55·09	..
Silver, hard ..	10·241	1·652	91·45	92·10	·2421	9·936	·209
„ soft ..	10·168	1·521	100·	100·	·2214	9·151	..
Tin, pressed ..	7·284	13·359	15·86	11·39	1·396	80·36	·202
Zinc, pressed ..	7·162	5·689	37·97	26·74	·5831	34·22	·202
Alloys.							
Brass .. about	8·4	8·266	22·18	18·45	·9938	49·72	..
German silver „	8·754	21·165	8·35	7·19	2·652	127·32	·024
1 Silver, 2 Plat.	12·021	24·661	5·22	6·17	4·243	148·35	·017
1 Silver, 2 Gold	15·203	10·988	9·26	13·84	2·391	66·10	·036
Carbon .. about	1·6	4196·	·2303	·0363	96·080	25240·	–·020

The line of carbon is derived from my own experiments and relates to the artificial carbons, such as are prepared for the Jablochkoff candles and arc lamps. The specific gravity is probably greater in the carbon of incandescent lamps, but it is scarcely possible to measure it, as the adhering film of air prevents its being properly weighed in water. It is probable also that the specific resistance is lower, but to discover this, either the specific gravity must be known, or the diameter, which is equally difficult to measure experimentally.

464. CORRECTION FOR TEMPERATURE.—It is convenient to adjust

resistances at the ordinary temperature, 60 Fahr., for which reason, also, the values are given in the formulæ and tables at that point. But it is necessary for many purposes to know the resistance corresponding to a temperature different from that at which observations are made, for temperature plays a very important part in the resistance of wires; in fact, it is difficult to get the same resistance twice for a piece of copper wire, if it is touched, or if the slightest change takes place in the room. Tables of correction are given in many works, but they never point out that these tables only give a part of the correction required. They deal only with the temperature of the wire itself, but leave out of sight altogether the variation which takes place in the *measurement instrument itself*, though this is one-tenth of that of the copper wire as regards external temperature, and greater than that of the wire as regards any heat produced by the current itself. The latter cannot be dealt with except by careful valuation in each case; but for ordinary resistance measurement, with small and momentary currents, the external action alone need be considered. Instruments for measuring resistance ought to have marked upon them the temperature at which they are correct, then the correction for actual temperature, say in copper wire, would be, not that for copper merely, as given in the usual tables, but this less the simultaneous variation of the German silver wire of the instruments. Thus for each degree Fahrenheit near about 60°—

Copper varies as 1 to	1·00215	log.	0·0009327
German silver varies as ..	1·00024	„	0·0003126
Combined correction at 60° ..	1·00191	„	0·0008287

The variation occurs not equally for each degree, but by a curve represented according to the experiments of the British Association Committee on Electrical Standards, by the formula for the resistance R at temperature t (Centigrade) from the resistance r at zero, $R = r\,(1 + a\,t \pm b\,t^2)$.

	a	b
Pure metals	0·003824	+ 0·00000126
Mercury	0·0007485	− 0·000000398
German silver	0·0004433	+ 0·000000152
Platinum silver	0·00031	

But for all ordinary purposes the correction above given will suffice, multiplying the decimal portion or the logarithm by the number of degrees (not by the logarithm of the degrees), and multiplying the resistance observed, for higher temperature, and dividing for lower temperature; adding or subtracting, as required, the logarithmic correction to the logarithm of the observed resistance.

Thus to correct from 60° to 32°, or the freezing point (zero Cent.) is 28° $\cdot 00215 \times 28 = 1 \cdot 0602$ for copper. The correct figure, 1·0605, differs very slightly from this, and the mode of correction is shown, § 470.

It is probable that these figures apply only to moderate heats, and Müller gives the following resistances for high temperatures of certain wires experimented on.

Iron.		Copper.		Platinum.	
0° Centigrade	640	0° Centigrade	814	0° Centigrade	1870
21° „ ..	691	21° „ ..	864	21° „ ..	1986
285° „ ..	1660	Slightly incandescent ..	2100	Slightly incandescent ..	4300
Dark red ..	3200	Carmine red ..	2450	Red hot	4700
Bright red ..	3650	Brick red ..	3300	Orange	5400
White hot ..	4880	Bright red ..	4700	Light yellow ..	6000

On the other hand, carbon, as in the incandescent lamp, has a resistance, when cold, just about double of that when at full light-giving temperature.

Specific heat, that is the quantity needed to raise unit weight of any substance 1 degree in temperature, *increases* as the temperature approaches the point of a change of physical state, such as fusion. But Siemens, in the course of his experiments on electric pyrometers, found the increase of resistance by heat reduced as the temperature rises, and that the resistance of a metal may be expressed as

$$R = \alpha \sqrt{T} + \beta T + \gamma$$

R being the resistance, T the absolute temperature (reckoned from absolute zero − 273·7° Cent. or − 470·66° Fah.), and α β γ are coefficients related to the particular metals.

465. DIMENSIONS OF WIRES.—For electrical purposes, in addition to the ordinary commercial considerations of weight, length, and strength, we must include electric resistance; so that if we fix upon a definite unit, which includes weight, length, and resistance, all considerations are resolved into mere multiples of that unit.

Although we may buy and speak of wires by their diameters, this principle means that we should think, not of their diameters, but of their sectional area, which varies in the ratio of the square of the diameter. We must, in fact, regard the wires, not as single cylinders, but as though they were built up of a series of parallel unit cylinders of definite properties. Of course, the metric measures would furnish the best system, but as this is practically out of the question, the best plan available is to take for the unit of measure the one-thousandth of an inch, already frequently so used, and called a "mil." Since wires are round, and the areas of circles increase as the squares of the diameters, we should regard the "mil" as a circular wire. Then, by squaring the diameter in "mils" of any wire, we obtain direct its area in circular mils—that is to say, the number of unit wires to which it is equivalent. To make the unit complete, its length must be defined, and the foot is the most convenient measure. But as in electricity we require to include in our unit, electric resistance as well as the weight, &c., it is still more convenient and generally useful to make weight, rather than diameter, the basis of the unit, and the most generally useful unit would appear to be a wire, 1 foot long, weighing 1 grain. By ascertaining the relation of this, for each metal, to the general circular *mil* foot, every necessary calculation can be readily effected. This relation is given as nearly as present knowledge allows in Cols. VI. and VII. of Table IX., p. 283.

466. WIRE GAUGES.—Wire is usually bought by Birmingham wire gauge. Here is, however, a name without an object belonging to it; for no one can tell what the Birmingham wire gauge is, and different dealers will differ two or three sizes, while, in the finer wires, it is a mere chance what will be obtained for any gauge asked for. The subject was taken up by a committee of the Society of Telegraphic Engineers and Electricians, whose report will be found in the Proceedings of the Society, Vol. viii. 1879, p. 476. It appears probable that the BWG originated in the sizes resulting from successive draws from the rod of iron, subsequently adjusted to diameters reducing by 8ths, 16ths, 32nds, and 64ths of an inch, and then by 10ths of the 64ths; but makers varied them to suit their purposes, and it is said employed different gauges for paying the workmen or for buying from those used in selling. The Committee suggest a new gauge based upon a logarithmic curve, in which each number is 25 per cent. heavier than the next lower: such a curve permits any unit of weight or diameter to be used, and it is proposed to make No. 0 the starting-point, with a diameter of 1 centimetre, or inch ·3937, which approximates the average existing values. The following table will show the differences in the gauges. Col. I. is that of Stubbs and Holtzapffel. II. is that of Messrs. Wynn, and is employed in Culley's work on

Telegraphy, and being generally known to electricians, I have used it here. III. is the theoretical original scale, arrived at by the late C. V. Walker, based on 640ths of the inch, and derived from a gauge supplied by Messrs. R. Johnson and Nephew, the well-known wire drawers, with small corrections to fit it to the theory. Col. IV. is the Committee's new scale, based upon Latimer Clark's logarithmic curve, and proposed to be called the B S G, or British Standard Gauge. The discrepancies increase in the higher numbers, which have been introduced long after the original gauges were established. The best plan is not to go by gauges at all, but adopt either the measured diameter or the weight of a given length, as is always done upon the large scale by electrical engineers.

WIRE GAUGES IN MILS.

Gauge.	I.	II.	III.	IV.	Gauge.	I.	II.	III.	IV.
	Stubbs.	Wynn.	Walker.	Clark.		Stubbs.	Wynn.	Walker.	Clark.
000	425·	375·	437·5	492·1	16	65·	65·	62·5	66·1
00	380·	350·	375·	440·2	17	58·	58·	56·3	59·1
0	340·	325·	343·8	393·7	18	49·	50·	50·	52·8
1	300·	303·	312·5	352·1	19	42·	43·	43·8	47·8
2	284·	280·	281·3	315·	20	35·	37·	37·5	42·3
3	259·	258·	250·	281·7	21	32·	32·	34·4	37·8
4	238·	238·	234·4	252·	22	28·	29·	31·3	33·8
5	220·	218·	218·8	225·4	23	25·	26·	28·1	30·2
6	203·	200·	203·1	201·6	24	22·	23·	25·	27·1
7	180·	182·	187·5	180·3	25	20·	21·	23·4	24·2
8	165·	165·	171·9	161·3	26	18·	18·5	21·9	21·6
9	148·	149·	156·3	144·2	27	16·	16·	20·3	19·4
10	134·	134·	140·6	129·	28	14·	14·	18·8	17·3
11	120·	120·	125·	115·4	29	13·	13·	17·2	15·5
12	109·	107·	112·5	103·2	30	12·	12·	15·6	13·9
13	95·	95·	100·	92·3	31	10·	11·	14·1	12·4
14	83·	84·	87·5	82·6	32	9·	10·	12·5	11·1
15	72·	73·	75·	73·9	36	4·	7·9	—	—

467. *Logarithms.*—In applying the principles of § 465, and in illustrating the formulæ based upon them, I employ logarithmic calculations. Some readers may think this very abstruse, but it is the simplest of all modes of calculation, and most accurate and rapid, while least fatiguing to the brain. Their use cannot be too strongly recommended to those who have to make many calculations of any kind, and who have not practised the use of the slide rule, which is in fact a logarithmic machine. The examples and formulæ, having their decimal values given also,

can be worked out in the ordinary manner by those who prefer to do so.

468. A WIRE is simply *a cylinder occupying a certain measurement of space.* The weight of the cylinder will depend upon the specific gravity of the material which fills the space.

A *cubic inch of water* weighs 252·456 gr., and this multiplied by 12 and by ·7854 gives us the weight of a circular inch-foot of water; and that multiplied by the specific gravity of any metal gives the weight of a circular inch-foot of that metal, and thus the datum for all required calculations. I will work this out in logarithms, taking, as the basis, copper, specific gravity 8·9, this being the average specific gravity of good copper wire:—

Cubic inch of water 252·456 ..	2·4021857
12 in. per foot	1·0791812
·7854, ratio of circle to square ..	$\bar{1}$·8950909
Circular inch-foot of water	3·3764578 = 2379·3
Specific gravity of copper 8·9 ..	0·9493900
Circular inch-foot of copper ..	4·3258478 = 21176·1

469. This divided by 1000 × 1000 = 1,000,000, gives the weight in grains of a wire of a circular *mil* one foot long. In this way are obtained the figures in Column II. of Table X. of the various constants required in calculations as to wires.

By dividing 1,000,000, the circular *mils* in an inch, by the weight of the circular inch-foot, we obtain the sectional area in *mils* (or number of *mils* it occupies) of a wire weighing one grain per foot. This gives Column III. of the Table of Constants.

1,000,000 = 10^6	6·0000000
Inch-foot of copper, 21176·1 ..	4·3258478
Mils per grain-foot, G.	2)1·6741522 = 47·22
sq. root	
Diameter of grain-foot	0·8370761 = 6·872

470. Assuming as correct the resistance of one foot-grain wire given in Table IX., we obtain all that is necessary to complete the data, viz. the resistance of the unit foot-grain wire, which I have calculated at 60° and inserted in Column IV. of Table X.

Resistance of soft copper,	
One foot-grain at 32°, ·2064 ..	$\bar{1}$·3147097
Correction for 28°, 1·0605	0·0255107
Unit resistance at 60°, U.	$\bar{1}$·3402204 = ·21889

471. **CONSTANTS OF UNIT WIRES.**—Table X. gives the principal constants required for calculations. Those for German silver and brass are for average values, and those of Col. IV. for the grain-foot resistance U ought to be determined for any particular sample if exactness is required. In the case of German silver it may vary 50 per cent., and in that of copper, in proportion to its conductivity.

TABLE X.—CONSTANTS OF UNIT WIRES.

	I. Specific gravity.	II. M Grains per *mil*-foot.	III. G Area in *mils* per grain-foot.		IV. U Resistance at 60° Fahr. of foot grain.	
			Mils.	Logarithm.	Ohms.	Log.
Water	1·	·0023793	420·29	2·6235422		
Copper	8·9	·0211761	47·22	1·6741522	·2189	‾1·3402204
Iron	7·8	·0185590	53·88	1·7314476	1·1634	0·0657173
German Silver	8·7	·0207003	48·31	1·6840229	2·6699	0·4264939
Brass	8·4	·0199865	50·03	1·6992629	·9938	‾1·9972763
Platinum ..	21·4	·051006	19·61	1·2923782	2·8879	0·4760559
Carbon	1·6	·003807	262·68	2·4194222	95·592	1·9802392

472. **FORMULÆ FOR WIRES.**—As the following formulæ differ in several points from those generally given to attain the same results, it may be explained that this is owing to the definite system of which these form a part. Most other formulæ are single ones, devised each for its own purpose and often based upon mere actual measures of particular wires, which often vary in quality. Those given here may have no actual superiority over these others, except as forming part of a definite system based upon mathematical truths, and linked especially to the conception of wires, not as each separate entities, but as consisting of collections of unit wires of definite property, thus giving to d^2 an extended meaning, from the mere square of the diameter of single wires to the number of units in all wires.

473. **SYMBOLS USED IN THE FORMULÆ.**—Let the following letters represent the requisite particulars.

W = weight in grains. $W \div 7000$ = weight in pounds.
w = ditto per foot. $= M \times d^2$ or $d^2 \div G$.
M = ditto per mil-foot $= m \times s$ or $1 \div G$ or $U \div u$.
m = ditto ditto of water = ·0023793 Log. ‾3·3764578.
d = diameter in mils (inch ·001) = square root of d^2.
d^2 = square of diameter = area in circular mils $= w \times G$.
G = area in mils of the grain-foot $= 1 \div M$ or $u \div U$.
g = ditto ditto of water = 420·29 Log. 2·6235422.

U

l = length in feet.
s = specific gravity. $= \mathrm{M} \div m$ or $\mathrm{U} \div (u \times m)$.
R = resistance in ohms at 60° Fahr. $\mathrm{U} \times l \div \mathrm{W}$.
r = ditto per foot $= \mathrm{R} \div l$.
U = ditto ditto of the grain-foot $= r \times w$.
u = ditto ditto of the mil-foot $= \mathrm{U} \times \mathrm{G}$ or see R.
R = specific resistance of cubic centimetre.
ohm $= u \times 0000016624$ Log. $^{-}7{\cdot}2207291$.
ditto for microhms, index $^{-}1$; for C G S units 2.
$R \times$ reciprocal of these constants gives u.
$s \times m$ gives all the data for weight, &c., so that from these two data all requisite information can be calculated.

474. DIAMETER.—To ascertain the *size*, or *gauge*, or the *diameter of any wire*, *d*, weigh and measure carefully any convenient piece, and reduce to grains per foot. Multiply this by the constant G in Column III. (47·22 for copper). This gives the sectional *area* in circular *mils*, d^2, and the square root of this is the diameter in *mils*, *d*.

$$d = \sqrt{w\,\mathrm{G}}.$$

Ex. 4 ft. weigh 3·15 grs.	0·4983106	
Divided by 4	0·6020600	
w, grains per foot	$^{-}1{\cdot}8962506$	= 0·788
G, constant for copper, 47·22 ..	1·6741522	
d^2, sectional area	2)1·5704028	= 37·10
d, diameter in *mils*	0·7852014	= 6·1

For other metals proper constants should be used.

Resistance of a length being known × by conductivity and ÷ by length in feet to reduce to resistance per foot as pure copper, $= r$; then

$\mathrm{G} \times \mathrm{U} \div r = d^2$. $\mathrm{G} \times \mathrm{U}$ for copper = 10·3365 Log 1·0143726
or $\mathrm{U} \div r = w \times \mathrm{G} = d^2$.

475. WEIGHT OR LENGTH.—*The diameter being known, to ascertain the* WEIGHT *of any length, or the* LENGTH *of any weight*, multiply the square of the diameter by Column II. of the Table, the grains per *mil*-foot. This gives the weight in grains per foot, from which all required weights and lengths are ascertainable by common arithmetic.

$$w = d^2\,\mathrm{M}.$$

Or, dividing the square of the diameter by the area of the grain-foot G, Column III., will also give the grains per foot.

$$w = \frac{d^2}{G}.$$

476. *For copper wire*, the *square of the diameter*, with following constants, will give the particular information in each case.

		Log.
Feet per pound, divide by d^2 ..	330560	5·5192502
Yards per pound, ditto ..	110187	5·0421289
Grains per foot, multiply by d^2	0·0211761	$\bar{2}$·3258478
Lbs. per 1000 feet, ditto	0·0030252	$\bar{3}$·4807498
Lbs. per mile, ditto	0·015973	$\bar{2}$·2033837
Lbs. per nautical mile, ditto	0·018414	$\bar{2}$·2651531

The same constants, used in the opposite manner, will give the *area*, and hence the *diameter of a wire*, of which any of these particulars are known.

The following constants also furnish useful data as to copper wire; they are, in fact, the resistances of a wire of one-thousandth inch diameter, of the length named, at 60°, and are to be divided by the sectional area in *mils*, d^2.

		Log.
Ohms per foot at 60°	10·3365	1·0143726
Ohms per yard	31·0095	1·4914939
Ohms per mile	54,577	4·7370065
Ohms per nautical mile at 60°	62,918	4·7987759
Ohms per lb. divide by d^4 ..	3,416,825	6·5336228
Feet per ohm, multiply by d^2	0·0967447	$\bar{2}$·9856274

477. RESISTANCE.—*To ascertain the* RESISTANCE *of any wire at* 60°, divide the unit resistance U, Column IV., by the weight in grains per foot. This gives the resistance per foot, which multiply by length required.

$$R = U \times \frac{l}{w}$$

Or, multiply U by the length in feet, and divide the product by the area multiplied by M, the grains per *mil*-foot.

$$\frac{U\,l}{d^2\,M} \quad \text{or} \quad \frac{U}{M} \times \frac{l}{d^2}$$

This last formula gives another constant, the resistance of the *mil*-foot at 60°, which might, if preferred, serve as the principal unit instead of the grain-foot.

478. CONDUCTIVITY.—Measure the resistance of any convenient

length, correcting for temperature to 60°. Divide by the length in feet, and multiply by the weight in grains per foot. This gives the resistance per grain foot, or specific resistance, by which divide the unit 0·21889. The quotient is the conductivity.

$$C = U \div \frac{Rw}{l}$$

The actual measurement of wire for its resistance, in order to ascertain its conductivity, may be effected on three distinct systems.

(1) The measurement of any length and reducing the length and resistance to the unit foot-grain or mil.

(2) By Clark's system. A standard wire of copper is mounted; its length or size is of no consequence, but its resistance is made 0·1516 ohm at 60°, being equivalent to a pure wire 100 in. long weighing 100 grains; the conductivity of any other wire is measured direct by balancing the necessary length against this, and will be as the square of its length in inches divided by its weight in grains. This has the advantage of requiring no correction for temperature, as both the wires vary alike, care of course being taken not to so pass current through as to act unequally on them.

(3) By a pair of stout clamps, forming one of the openings of a Wheatstone's bridge, and best fixed exactly 1 foot apart; the resistance per foot is thus measured, and multiplied by its weight in grains, gives the actual foot-grain resistance.

Example. The 4 feet of wire, weighing 3·15 grains, used § 474, gave a resistance, at 72° of ohms, 1·349.

Resistance, 1·349	0·1300119	
72 − 60 = 12°, correction, 1·0255	0·0109357	
R, resistance at 60°	0·1190762	= 1·315
w, grains per foot, 0·788	$\bar{1}$·8962506	
	0·0153268	
l, length 4 feet	0·6020600	
Res. per grain-foot at 60°, ...	$\bar{1}$·4132668	= 0·25898
Unit grain-foot resistance, 0·21889	$\bar{1}$·3402204	
Actual „ resistance, 0·25898	$\bar{1}$·4132668	
Conductivity	$\bar{1}$·9269536	= 84·5 per cent.

Or, measure and weigh any length of which the resistance is known, and multiply U by the length, and divide by weight per foot, which gives the equivalent resistance as pure copper, which divide by the actual resistance.

The relative conductivity of any metal as compared with any other taken as standard can be calculated thus for equal weights or equal sections;

$$\frac{\text{U or } u \text{ of standard} \times 100}{\text{U or } u \text{ of substance}} \quad \text{thus} \quad \begin{matrix}\text{silver} & u = \\ \text{zinc} & u = \end{matrix} \frac{9 \cdot 151 \times 100}{34 \cdot 2} = 18 \cdot 45$$

Cols. IV. and V. of Table IX. are obtained in this way.

479. Copper.—This varies very greatly in its electric properties, ranging in conductivity from 97 per cent. as low as 50. It is of great importance to attend to this, for in making an instrument, be it a galvanometer, an electro-magnet, or a coil, resistances should be duly balanced with the battery power employed, while it is of great importance not to use wire unnecessarily large, because this increases cost and diminishes the effect; so that by not attending to this we may obtain only half the effect we should by securing good wire.

Mathiessen gives the relative conductivity of various coppers as compared with hard-drawn silver:

Pure copper:		Temperature.
Oxide reduced by hydrogen	93·0	at 18·6 C.
Electrotype, not melted	93·46	„ 20·2 „
„ fused in hydrogen ..	92·76	„ 19·3 „

The conducting power increased about 2 per cent. by annealing the wires.

Impure, or commercial coppers:		Temperature.
Containing red oxide, melted in air	73·32	at 19·5 C.
„ 0·95 of phosphorus ..	23·24	„ 22·1 „
„ 2·80 per cent. of arsenic	13·14	„ 19·1 „
„ 1·60 per cent. of zinc ..	56·98	„ 10·3 „

Taking the pure unmelted electrotype copper as standard, or 100,

Spanish (Rio Tinto), containing arsenic, iron, lead, &c., was	14·24
Russian, with traces of same	59·34
Tough cake	71·03
Australian, Burra Burra	88·86
American, Lake Superior	92·57

These figures show that excellent commercial wire may be very bad for electrical purposes.

TABLE XI.—PROPERTIES OF COPPER WIRE. SP. GR. 8·9.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
B. W. Gauge.	Diameter.		Area in circular Mils = unit wires. (d_2)	Weight.		Length.	Resistance as Pure Copper at 60° Fahr.		
Col. II. of Table.	In Mils. = ·001 in. (d)	Milli-metres.		Grains per foot. (w)	Pounds per 1000 feet.	Feet per pound.	Ohms per 1000 feet.	Feet per Ohm.	Ohms per pound.
centimetre	393·7	10·	155003·	3282·4	468·92	2·13	0·0667	14996·	·00014
¼	250·	6·37	62500·	1323·5	189·07	5·29	0·1654	6046·5	·00088
6	200·	5·08	40000·	847·1	121·01	8·26	0·2584	3869·8	·00214
inch.	180·	4·57	32400·	686·1	98·02	10·20	0·3190	3134·6	·00326
8	170·	4·31	28900·	612·0	89·46	11·18	0·3495	2861·0	·00391
9	155·	3·94	24025·	508·8	72·68	13·76	0·4302	2324·3	·00592
10	140·	3·55	19600·	415·0	59·29	16·87	0·5274	1896·2	·00889
⅛	125·	3·17	15625·	330·9	47·27	21·16	0·6615	1511·6	·01400
11	120·	3·05	14400·	304·9	53·56	23·28	0·7178	1393·1	·01648
12	110·	2·79	12100·	256·2	36·69	27·32	0·8543	1170·6	·02334
	100·	2·54	10000·	211·8	30·91	33·06	1·0336	967·5	·03417
13	95·	2·41	9025·	191·6	27·30	36·63	1·1453	873·1	·04195
14	85·	2·15	7225·	153·0	21·12	46·28	1·4472	691·0	·06698
15	75·	1·92	5625·	119·1	17·02	58·77	1·8376	544·2	·10799
	70·	1·778	4900·	103·76	14·82	67·46	2·1095	475·1	·14241
16	65·	1·651	4225·	89·47	12·78	78·24	2·4465	408·8	·19141
1/16	62·5	1·587	3906·	82·72	11·82	84·62	2·6462	386·7	·22392
	60·	1·521	3600·	76·23	10·89	91·82	2·8712	348·3	·26370
17	57·	1·440	3249·	68·80	9·83	101·75	3·1814	314·3	·32369
	55·	1·397	3025·	64·01	9·15	109·28	3·4170	292·0	·37340
18	50·	1·274	2500·	52·94	7·563	132·22	4·1346	241·9	·54669
19	45·	1·143	2025·	42·88	6·126	163·25	5·0927	196·0	·83324
	43·	1·092	1849·	39·16	5·593	178·78	5·590	178·9	·99910
	42·	1·066	1764·	37·36	5·236	187·39	5·8597	170·7	1·0981
20	40·	1·016	1600·	33·88	4·840	206·60	6·4603	154·8	1·3347

millimetre	39·37	1·	1550·	32·823	4·689	213·26	6·669	151·0	1·429
21	35·	·889	1225·	25·941	3·705	269·84	8·438	118·5	2·278
22	32·	·813	1024·	21·684	3·101	322·81	10·094	99·1	3·259
	31·62	·803	1000·	21·176	3·025	330·56	10·336	96·7	3·417
	30·	·762	900·	19·059	2·729	367·29	11·485	87·1	4·218
23	28·	·711	784·	16·602	2·371	421·63	13·184	75·9	5·559
24	25·	·635	625·	13·235	1·891	528·90	16·539	60·5	8·747
25	23·	·584	529·	11·202	1·604	624·88	19·540	51·2	12·210
26	19·	·483	361·	7·648	1·092	915·78	28·633	34·9	26·219
27	18·	·457	324·	6·845	·991	1020·3	31·902	31·4	32·549
28	16·	·406	256·	5·421	·774	1291·3	40·377	24·8	52·137
29	15·	·381	225·	4·765	·681	1469·1	45·940	21·8	67·493
met.-gram.	14·9	·379	222·13	4·704	·672	1488·1	46·534	21·5	69·250
30	14·	·355	196·	4·151	·593	1690·4	52·727	19·0	88·943
31	12·	·305	144·	3·049	·435	2295·6	71·780	13·9	164·78
32	10·	·254	100·	2·118	·303	3305·6	103·36	9·7	341·68
34	9·6	·244	92·16	1·952	·279	3586·8	112·16	8·9	402·29
	9·	·228	81·	1·715	·246	4081·0	127·90	7·8	520·78
35	8·7	·221	75·69	1·603	·229	4367·3	136·56	7·3	596·41
	8·	·203	64·	1·355	·194	5165·0	161·51	6·2	834·19
36	7·9	·200	62·41	1·322	·189	5296·6	165·62	6·0	877·23
Foot-grain	**6·872**	**1·75**	**47·22**	**1·**	**·14286**	**7000·**	**218·89**	**4·5684**	**1532·2**
37	6·7	·170	44·89	·951	·136	7363·7	230·26	4·3	1695·6
38	5·8	·147	33·64	·712	·102	9826·4	307·27	3·3	3019·3
	5·5	·139	30·25	·641	·092	10902·	341·70	2·9	3734·0
	5·	·127	25·	·529	·0756	13222·	413·46	2·42	5466·9
39	4·2	·106	17·64	·374	·0534	18739·	585·97	1·71	10981·
	4·	·106	16·	·339	·0484	20660·	646·03	1·55	13347·
40	3·9	·099	15·21	·322	·0460	21732·	679·58	1·47	14769·
41	3·3	·084	10·89	·231	·0329	30354·	949·17	1·05	28812·
	2·	·0508	4·	·085	·0121	82640·	2590·1	0·39	213562·
Mil.	**1·**	**·0254**	**1·**	**·0211761**	**·0030252**	**330560·**	**10336·5**	**·0967447**	**3416825·**

480. Table of Copper Wire.—This is calculated on the formulæ, §§ 474–7, for the most useful sizes of copper wire, but its readings may be translated into the values of other metals by the following constants:—

			Log.
1. Weights. Multiply by	Iron	·87641	$\bar{1}$·9427046
	German Silver ..	·977538	$\bar{1}$·9901293
	Brass	·94382	$\bar{1}$·9748893
2. Lengths. Multiply by	Iron	1·14003	0·0572954
	German Silver . ..	1·02298	0·0098707
	Brass	1·05952	0·0251107
3. Resistance. Multiply by	Iron	5·3149	0·7254969
	German Silver ..	12·2009	1·0863826
	Brass	4·54	0·6570559

4. Length of Resistance (Col. IX.) divide by the constants in 3, which are the conductivities, copper being 1. In like manner the conductivity of any commercial copper or other metal will give the correction to employ.

The data chosen have been those most extensively available; thus 1000 feet is taken because the change of the decimal point converts the value into that of 1, 10, or 100, while multiplying by 5·28 converts it into a mile. The last column is likely to be very useful to those who wish to select wires for any purpose, especially as multiplying by 12 gives very closely the value in German silver. The figures in the *foot-grain* and *mil* lines are the constants for use in the formulæ. The diameters are shown in millimetres for comparison when required; while the millimetre and metre-gramme lines furnish constants which will enable the calculations to be made in the metric measures in the same manner as is described for the foot-grain system.

481. Resistance of Liquids.—For equal dimensions this is vastly greater than that of metals, but it is subject to the same laws; it varies inversely as the sectional area, and directly as the length. Therefore, by doubling the area, or what is frequently the same thing, doubling the size of the plates, we halve the resistance, or may double the distance apart without increasing the resistance. This holds exactly true only when the plate fills a cell of square section, as to which see § 484. The law also holds true only as to the real liquid resistance, the molecular motion in the liquids themselves. There are really three elements of resistance in most liquids:—

(1) The true liquid resistance just spoken of, and to which alone this section refers.

(2) The resistance at contact of the plate and liquid which varies the active area, as when a gas is given off and covers

part of the surface: this may be regarded as analogous to dirty surfaces or bad soldering with wires, &c.

(3) An absorption of energy when an electrolyte is decomposed, which has been given the confusing name of "polarization" of plates, as to which see § 261.

The resistance of a porous cell is really due to the reduction of the area of the liquid: hence, if this be measured in ohms, it will be different if the liquid is a good or bad conductor, as the real thing measured is the conducting capacity of the liquid absorbed in the pores.

Heat has the opposite effect in liquids to that upon metals: for heating *diminishes* the resistance. In some cases the resistance at 32° is three or four times as great as at 212°, and in the case of soda lye, nearly 100 times as great.

482. With the exception of metals when fused, or like mercury, liquid at ordinary temperatures, liquids appear not to conduct electricity at all, except when undergoing electrolytic decomposition. Thus oils, alcohol, &c., are very perfect insulators, and even water, when absolutely pure, has no power of conduction, but when containing gases or saline bodies it breaks up and conducts: then the degree of resistance offered depends upon the specific property of the substance, and the degree of concentration of the solution.

483. I have collected the most important information available in the following Table, from which it appears that in some cases saturated solutions are the best conductors; in others there is a particular degree of saturation at which resistance is least, conductivity diminishing both above and below it. These latter are deliquescent or extremely soluble salts. Probably this may throw light upon the nature of solution and upon the question whether crystalline bodies dissolve as such, with their water forming part of the dissolved molecules, or whether only the salt itself is dissolved. Many chemical facts tend to show that salts which crystallize in two or more forms with different amounts of water, have different solubilities in the different forms.

484. CONDUCTION THROUGH LIQUIDS.—It may be supposed that electricity takes only the shortest and straightest path, and that in a liquid with two plates in it, the current would be confined to the stratum of liquid lying between the plates. This is not the case. Electricity divides itself through every path open to it in the ratio of the resistances of each path. Therefore if small plates are immersed in a large vessel, every particle of liquid in the vessel will form itself into a path for current. This may be tested by means of two wires fixed into a frame

and connected to a galvanometer. On dipping these into a liquid through which current is passing they will form part of the circuit, replacing the liquid lying between them, although they have no metallic connection to the plates or battery. According to the part of the liquid they are placed in will be the amount of current they intercept, and by calculation of the various elements of the current, this will show the relative quantities of electricity passing in different parts of the vessel.

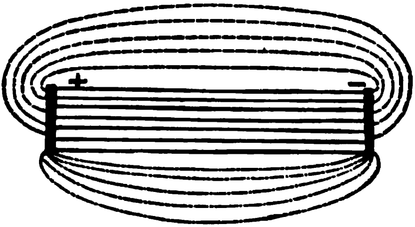
RESISTANCES OF LIQUIDS AND INSULATORS.

	I.	II.	III.	IV.	V.
	Substance.	Resistances compared to Copper.	Specific Resistance.	Temp. Centigrade.	Variation per cent. per Deg. C.
1	Copper, hard	1·	1642·	0°	·377+
2	Mercury	58·20	96146·	"	·072+
3	Copper sulphate, saturated	16,855,520·	CGS units per cub. cent.	9	
4	" " diluted to half ..	26,327,637·	§ 446	"	
5	" " 1 lb. per gallon ..	18,450,000·			
6	" " Cu SO_4 + 45 H_2O	.. ..	$1·95 \times 10^{10}$	22	
7	Zinc sulphate, saturated	15,861,267·	..	13	
8	" " diluted to half	12,835,836·	..	"	
9	" " Zn SO_4 + 23 H_2O ..	.. ..	$1·87 \times 10^{10}$	23	
10	Sodium chloride, saturated	2,903,538·	..	13	
11	" " diluted to half ..	3,965,421·	..	"	
12	H_2SO_4 ·2 per cent. in water	.. ..	$4·47 \times 10^{10}$	..	·47 —
13	" 8·3 " "	.. ..	$3·32 \times 10^{9}$	..	·653 "
14	" 20 " "	.. ..	1·44 "	..	·799 "
15	" 35 " "	.. ..	1·26 "	..	1·259 "
16	1 vol. to 11 of "	1,032,000·	..	20	
17	Nitric acid, sp. gr. 1·264	1,606,000·			
18	" " 1·31	976,000·	..	13	
19	Distilled water	6,754,208,000·	$7·18 \times 10^{10}$	22	·47 "
20	Rain "	40,652,723·			
21	Selenium, vitreous	.. ..	$6· \times 10^{18}$	100	
22	Glass	variable	$2·27 \times 10^{16}$	200	
23	Mica	.. ..	$8·4 \times 10^{22}$	20	
24	Gutta-percha	Latr. Clark	$4·5 \times 10^{23}$	24	
25	"	Everett	$3·53 \times 10^{23}$	"	see § 94 (b)
26	"	"	$7· \times 10^{24}$	0	
27	Shellac	.. ..	$9· \times 10^{24}$	28	
28	Hooper's material	.. ..	$1·5 \times 10^{25}$	24	

Fig. 72 shows the facts: even the backs of the plates take part in the action, and it is most active upon the edges from the same causes which render points and edges active in static electricity, § 63. Hence, contrary to common opinion, the backs of battery plates are to some extent active. Mount a pair of plates with one side varnished, either as a battery or in a coppering cell with a galvanometer, and note the effect when the varnished sides or the bare sides are presented to each other.

485. Earth Connection.—These facts explain why the resistance of a telegraphic return current by earth plates is so small as to count for nothing as compared with that of the wire. The return current passes through the liquids of the earth and sea just as in the case of a common decomposition cell, and its plates are subject to the same effects of polarization, § 260, but the lines of current are not limited; they spread out in all directions, as in Fig. 72, and the result is that the only actual resistance is of the order 2 and 3, § 481. There is another theory favoured chiefly by mathematicians, that the earth may be regarded as an infinite reservoir, § 28, or else as an infinite pair of condensing plates in which the potentials set up in the wire are lowered to zero.

Fig. 72.



But if we enclose a liquid, or moist earth in a tube, we find that tube is a conductor, and it acts in all respects as a wire does; we may lengthen it or add tube to tube, still the same, still the resistance as it grows obeys the definite laws: why then set up a new idea when we deal with the earth? this is we know a mass of electrolytes, and we know also that the plates act exactly as two plates in a solution do. The analogy has another view: if we use a copper earth plate in London and a zinc earth plate at a distance and in such a direction as eliminates the disturbing action of the natural currents of the earth, these plates act precisely as though they were in a cell, they produce a current traversing the wire, and if we soak the earth around the copper plate with a copper salt, we get all the effects of a Daniell cell: is it not obvious then that the intermediate earth is acting precisely as does the liquid in an ordinary cell and completing the circle of the current?

486. The following description is that of an instrument I devised for measuring the true electric resistances of liquids and eliminating all disturbances. It is really a Wheatstone's bridge, or may be used with a differential galvanometer. Three glass

cells are connected together by two tubes of different lengths and mounted upon a stand, with connecting screws close to them provided with a vertical hole. These are for the plates or conductors attached to a wire which can be easily put in position. A resistance coil is placed in the circuit of the shorter tube, so that the current which enters at the middle cell and divides through the two tubes may be equalized, thus causing exactly the same polarization effects in both branches: if we regard the middle cell as — and the two tubes as the arms A C in Fig. 64, the action is evident: the extra resistance of the coils is exactly equal to that of the extra length of the longer tube. In order to obtain definite measures, the instrument is first charged with mercury, and thus a standard of comparison is obtained which dispenses with any accurate measures of the tubes or liquids, for the liquids are really compared with an equal bulk of mercury under exactly the same conditions, and these conditions equivalent to a known standard resistance. Open oblong cells may be used in place of tubes, provided that the plates completely fill the cross section; in this case the two sides of the middle plate distribute the two currents.

487. HEATING OF WIRES.—The law of the heat developed by the current is explained p. 236 as $C^2 \times R$, or $E \times C$, the unit being the joule, § 390, expressed in any desired form. This relates to the "quantity of heat" generated per second. The actual effect or rise of temperature in different substances produced by this quantity of heat is described pp. 218–220. It is necessary now to consider what becomes of this heat, and the ultimate effect, which for practical reasons may be most conveniently studied as relating to *copper* conductors, this becoming nowadays a most important subject.

This matter has undoubtedly received much attention from those engaged in electric lighting, but the information accessible is very slight. It is no doubt a valuable professional and trading knowledge; it also requires some very extensive experiments or observations, and these are apt to be regarded as private rather than public property. There is therefore at present very great difference of opinion, and I submit the following statements in great degree as suggestions, and subject to further advance in knowledge.

488. *Dissipation of Heat.*—Heat always passes away from a body of higher temperature to its surroundings of lower temperature; it does so at a *rate* dependent on the difference of temperatures, and upon the specific properties of surrounding bodies. There are three modes of transmission, *Conduction*, *Convection*, and *Radiation:* these must be studied in works treating

of heat, but a slight sketch of their relations to electric conductors is necessary, because each process has its own part to play.

Conduction is the process of transmission from particle to particle of a substance, always from the hot part to the cold, therefore, in the case of conductors, from the interior radially towards the surface.

Convection is the heating of molecules of gas or liquids in contact with the surface, which, becoming lighter, rise and give place to cooler molecules, thus carrying the heat away in a stream.

Radiation is the constant escape of heat from the surface across space, or through air, &c., which is not itself heated, but transfers the energy of heat to surrounding surfaces which are capable of receiving it and reproducing it as heat.

489. *Conduction of Heat* is effected from molecule to molecule much as electricity is, and the conductivities of metals are in closely the same order for heat as for electricity, though the rate of transmission is much smaller. The time of cooling of similar bodies is as the square of their linear dimensions, therefore in the case of electric conductors, the rate of cooling of the interior portion will be as the squares of their radii (or diameters), which means *as their sectional areas*, subject, of course, to other considerations. It is evident, therefore, that several small conductors will be cooler than one equal to the sum of them.

Fig. 28, p. 88, may be regarded as the section of a conductor, showing successive shells of the substance transmitting the heat from one to the other.

Insulating materials conduct heat badly as well as electricity, therefore they tend to retain the heat in the wire: most of them are also liable to injury by the heat, and therefore their nature limits the permissible temperature of the conductor: it is obvious that their thickness should be as small as is consistent with effectual insulation.

Iron would evidently be greatly inferior to copper as a conductor for large currents, not merely on account of its lower conducting power necessitating an equivalent increased weight, but because this increased size would retain the heat in the conductor.

One effect of the difference of the heat at the inner and outer parts of the conductor is to make the different parts unequal in conductivity, tending, as it were, to thrust a larger part of the current to the outer portion of the conductor; this again tending to the production of greater heat in these parts, and thus to the restoration of equilibrium. The distribution of heat in the section of the conductor will certainly not be that of a body first heated and then allowed to cool, but one of nearly equal temperature throughout, accompanied with frequent small changes in the distribution of current throughout the mass.

490. CONVECTION OF HEAT.—When a conductor is surrounded by a liquid, the same action occurs as may be seen in water heated in a metal vessel, where a continuous stream of heated particles runs upwards: therefore in a large mass of water the heat of a conductor would be kept down nearly to that of the water, at its surface, and at its interior in proportion to the property of conduction and size. In air the same action occurs, and in other gases it appears to occur at a rate related to their specific gravity, hydrogen having the greatest cooling action.

If two pieces of platinum wire of equal dimensions and resistance are enclosed in tubes containing, 1, air, 2, hydrogen, the same current passing through them will raise 1 to red heat, while 2 remains dark. If the two tubes are placed in equal quantities of water and the current passed through both, the water surrounding 1 will be more heated than that around 2; though the R of each was the same at first, wire 1, becoming more highly heated, its resistance is the greatest, and therefore in it the same current develops greater heat.

Dissipation of Heat by Convection plays an important part in conductors exposed to the air, and care should be taken to facilitate the action by not placing them close to ceilings or where circulation of air is difficult. It is evident also that thin strips of metal placed vertically will be kept more cool than the same mass of metal in a solid rod.

491. RADIATION OF HEAT.—It is considered that this action is always going on from all bodies, each emitting and each absorbing heat, with a tendency to bring all to the same temperature. The same conditions facilitate emission and absorbtion, and the chief of these conditions appear to be the nature of the surface. The subject of radiant heat or energy is of great importance in the generation of light, but as regards conductors it is of interest only in so far that its laws show that the metal surface, if exposed, should not be polished, but is best blackened with lampblack and size, and that if enclosed, the outer surface should be of such a nature as is known to assist radiation, and that such forms should be employed as give large surface if possible. Fig. 28 will also convey an idea of radiation, + being the conductor surrounded by air.

492. SAFE CURRENT IN WIRES.—It is evident that these three actions have very different bearing in different cases. With small wires exposed to the air, convection and radiation are of most consequence. With large and covered conductors radia-

tion may be of great importance; but with conductors insulated and placed underground, conduction, and that the conduction of the materials of the earth, will be the principal agency.

No definite laws of relation of current to size of conductor are possible: the conditions must be adapted to each order of circumstances, and this adjustment is now to be considered.

493. Willoughby Smith gives an experiment which besides its bearing upon safe current will serve as an example of various calculations. Current was transmitted from a dynamo machine to an arc lamp, through a conductor 50 yards in length, insulated to a thickness of ·065 of an inch, the two parts being allowed to touch at one point of the circuit, at which if the heat of the conductor were too great, the insulation was softened and the wires made contact. Conductors of three sizes were used. When the resistance was 0·28 ohm and current 27 ampères the conductor failed in 25 minutes; with 0·21 ohms and 30 ampères in 40 minutes, and with ·07 ohm and 33 ampères no injury was sustained.

Assuming the conductivity to be 96 per cent., we have by § 474

l	R.	$\times \frac{\cdot 96}{100} = r$	d^2	w	Ampère	
					”	per mil.
150 feet	·28	·001791	5768·	102·22	27	·00468
	·21	·001344	7691·	162·86	30	·00390
	·07	·000447	23609·	448·56	33	·00143

This latter value is inserted in the list of values for safe current, and appears to confirm the higher estimate; but it cannot be trusted to that end, as it relates only to a wire of 151·9 mils diameter, or about No. 9 B.W.G.

494. The Provisional order limits current to 2000 ampères per square inch in section, which is 1,273,235 circular mils. A proposed specification for Nottingham says 1750, others give 1000, while Fleeming Jenkin says 500, but would not object to 800, and considers 1200 the limit of safety; there is also the value of Mr. Siemens, 3 square millimetres per ampère, and the experiment § 493, all of which I will reduce to the value in circular mils.

Ampères per sq. inch.	Circular mil.	Mils per ampère.
2000 =	·0015708	636·617
1750	·0013744	727·574
1200	·0009210	1085·75
1000	·0007854	1273·24
800	·0006288	1591·57
500	·0003927	2546·47
Siemens	·0014186	704·92
W. Smith	·0014313	732·12

495. As 1 grain per foot means 47·22 mils (by § 476), 1000 ampères per square inch means 26·962 grains per foot per ampère, which figure or its Log 1·4307568 would serve as a basis for calculations as to size of conductors, multiplying it by any preferred value.

496. But considering how wide the range of difference of the above figures is, it will be more convenient to take 1000 ampères per circular inch (which is nearly Professor Jenkin's limit of safety) as the datum; this makes all the requisite calculations and data decimal ones connected to the system and formulæ of wires already used in these pages. Then we have as unit a wire 31·623 mils in diameter (a small 22 B.W.G.), which is simply the "mil" unit of the previous formulæ and the following data multiplied by 1000.

	Mil-current	ampère	·001	Log.	$\bar{2}$·0000000
A	Mils per ampère (*ampère foot*)		1000·	„	3·0000000
w	Weight, in grains per foot, per ampère ..		21·275	„	1.3258478
	„ lbs. per 1000 feet, ditto ..		3·025	„	0·4807498
	Resistance per ampère foot at 60° Fahr.		·01034	„	$\bar{2}$·0143726
J	Heat in ditto, per second, Joules				
	Multiplied by square of ampères ..		× C^2	„	of C × by 2
	Correction for temperature per deg.		1·00215	„	0·0009327
H	Rise per second in degrees Fahr.		·03321	„	$\bar{2}$·5080055

It is evident that these last values must be reckoned, not at the temperature of the surrounding air, but at the limit of temperature of the metal in full work.

497. *The size of the conductor must modify the mil-current:* that is to say § 489 shows that as the size of conductors is increased the specific capacity lowers: greater area, more metal must be provided *per ampère.* The law which governs this is not yet clearly settled.

The question is how to balance generation and dissipation of heat; to secure a defined equal temperature in conductors carrying different currents. The dissipation of the heat is in fact, whatever the mode, a function of *surface*, and in rods, square or round, *surface* increases *as the diameter* only, while area, or current-carrying power, increases *as the square of the diameter:* therefore with equal mil-currents, the heat in the conductor increases as the square of the surface through which it is to be dissipated. To make the surface ratio equal for large and small currents the area would have to be increased as the square of the current, which would be largely increased expense and unnecessary capacity. The true law is undoubtedly something between these two limits.

Professor Forbes says that as $C^2 = d^3$ the proper law should be C = square root of d^3, but Siemens says that experiment does not agree with this formula and that it does show that the law is C = d, which means that the section and weight should increase as the square of the current with the disadvantage just described.

498. *My own suggestion as to the problem* is that the ratio of area to current (which shall maintain equal temperature in the conductor) will be described by a logarithmic curve in which the ampère area will be gradually increased; the effect of this is, by reducing the mil-current, to lower the resistance per ampère, and therefore also the *heat generated;* on the other hand, the ratio of surface will be greater than that due to equal mil-currents, and therefore the escape of heat will be less obstructed; the two will combine in giving the conductor of the least weight which will be effective under the circumstances. Such a curve would probably be of this character

$$d = \sqrt{C \times Ck},$$

in which k would be a value to be determined by experiment. In other words the mil-current would be gradually lowered, or the ampère area increased in some ratio of C. Of course the initial mil-current would be different according to whether bare wire were used, or insulation of different kinds, and also the curve would be steeper, that is k would be greater, for insulated than for exposed conductors: to construct a general formula, therefore, other elements would have to be included.

499. I have not the experimental facilities for determining this matter, but I should suggest that it is one which should be studied by examining the *surface temperature* produced in conductors of various dimensions by different currents, and it appears that this might be conveniently done by means of a single thermo-element composed of a pair of thin broad plates, the junction of which could be applied parallel with the axis of the conductor: the galvanometer and thermo-pile would have to be well insulated to avoid any leakage of current from the conductor.

500. Cost of Conduction.—The amount of heat to be generated in the conductor has another bearing: the greater the heat in the conductor the greater is the loss of energy in transmission; that is, as explained, § 390, it is as the square of the current forced through a given conductor, or rather it is greater than this by the diminished conductivity due to the heat itself. This is therefore a question of *continuous working expenses.* On the other hand, if the capacity of the conductor be increased, so

as to reduce this expenditure of energy, there arises the question of capital outlay, and interest.

The determination of the relative importance of these two depends upon the conditions of each particular case. If the conductor is to be regularly worked to its full capacity, of course the working expenses are the most important. If the conductor is to be employed only a part of the time, the capital outlay is a serious consideration, and it would be better to endure a higher working cost than in the other case. The cost per electric horse-power, § 391, at any given place, and the cost of the conductor at the same place are variable elements upon which also the decision depends.

Siemens estimates the cost of electric energy in London at about one shilling per 10,000 Joules, and says that practice allows the conductors to have about one-tenth the resistance of the lamps to be supplied.

501. Sir W. Thomson's law on this is that the total cost is lowest when

$$\text{Cost of energy} = \text{Cost of conductor.}$$

That is to say, (1) the cost per horse-power of steam or other motor + the cost of transforming it into electric energy by the dynamo machine is reduced to some unit of time, as per hour or year: this multiplied by the units of energy expended in the conductor gives the cost of energy. (2) The interest on cost of conductor, and the expense of repairs and depreciation taken for the year, or divided by the number of hours of working, gives the other side of the equation, and the two together are the cost of transmission of the current.

502. *Equal currents can transmit different quantities of energy.* A given conductor will carry different currents, and the expenditure of energy in the transmission will then increase as the *square of the current*, but will remain an *equal proportion of the energy transmitted;* this is the meaning of the statements quoted § 423. But there are conditions in which the same conductor will transmit greatly increased energy while expending no more within itself. This depends on the increase of E M F, and a proportional increase in the total resistance.

Let two points, generator and receiver, each of 1 ohm R, be connected by a conductor of 1 ohm. Now an E M F of 3 volts produces C = 1, and 1 Joule energy will be expended in the conductor. Let the generator be so altered as to generate 2000 volts, and the receiver to utilize this E M F, raising the resistance of generator and receiver to 1999 ohms. We have still only a current C = 1, expending 1 Joule energy per ohm, losing therefore still only 1 in the conductor, but while passing into the receiver, utilizing so much as corresponds to its proportion of the total resistance: the loss of energy in this case is in the generator, which necessarily has a higher resistance than in the first case.

The result is that, the higher the E M F employed, the greater the economy of electrical work. But though this is theoretically true, the difficulties of insulation and the extra cost of overcoming these difficulties, and the great danger to life of very high E M F, will probably prevent this fact from having the practical importance attributed to it by some electricians.

503. But this does not give electricity the asserted advantage over water, as a transmitter of energy: precisely the same conditions apply to water in pipes under pressure, and even in this case, the limit imposed by risk of bursting the pipes is the strict analogue of the difficulty of insulation with electricity. The real advantage electric transmission has over hydraulic is not a theoretical one, or one dependent on any difference in the nature or laws of transmission; it is due to the fact that electricity has no mass of matter in motion, it has no momentum, and its conductors are smaller, more manageable, and less costly, while not exposed to risk of freezing.

P.S.—An Order in Council appoints the following dimensions as the legal wire gauges after 1st March, 1884.

No.	Inch.	No.	Inch.	No.	Inch.	No.	Inch.	No.	Inch.	No.	Inch.
7/0	·500	1	·300	11	·116	21	·032	31	·0116	41	·0044
6/0	·464	2	·276	12	·104	22	·028	32	·0108	42	·0040
5/0	·432	3	·252	13	·092	23	·024	33	·0100	43	·0036
4/0	·400	4	·232	14	·080	24	·022	34	·0092	44	·0032
3/0	·372	5	·212	15	·072	25	·020	35	·0084	45	·0028
2/0	·348	6	·192	16	·064	26	·018	36	·0076	46	·0024
0	·324	7	·176	17	·056	27	·0164	37	·0068	47	·0020
		8	·160	18	·048	28	·0148	38	·0060	48	·0016
		9	·144	19	·040	29	·0136	39	·0052	49	·0012
		10	·128	20	·036	30	·0124	40	·0048	50	·0010

CHAPTER VIII.

ELECTROMOTIVE FORCE.

504. To Measure Electromotive Force.—This has to be done in the terms of some standard cell, usually the Daniell, the force of which is known, but if the exact resistance internal and external, of the circuit and the current generated be known, Ohm's formula $C \times R = E$ gives the force in volts, but as the force and resistance are constantly altering in a working battery, this process gives us the actual force at the time, not the *potential* E M F of the battery.

505. The same process may be used with *small resistances* and full currents, but in that case the internal resistance must be included in the totals. Both rules depend on the law that for equal currents the force is in direct proportion to the total resistance. By carefully measuring the total resistance in the case of a Daniell cell and dividing this by 1·079, we get a constant representing the force of 1 volt, and dividing the resistance, which with any other cell gives the standard fixed deflection (on the same instrument, of course), by this constant we get the force of the cell under trial in the same manner as described more fully below as to Wheatstone's process.

506. With a very *delicate sine or tangent galvanometer* and a large resistance, the amount of which need not be known provided it is always the same, the electromotive force is proportional to the sine or tangent of the angle of deflection, and having once ascertained the angle given by a Daniell, and from it that due to 1 volt, the instrument can be marked, or a table made of the deflections, so as to read off direct in volts the electromotive force causing the deflection. If the resistance is made very large the internal resistance of the cell may often be neglected if not known. See § 511.

507. *Wheatstone's plan* is available either with large or small resistances: it depends on the production of two constant deflections. In this and the following cases I will use in the formulæ capital letters for the standard cell and small letters for the one to be measured, E, *e* being force in volts, R, *r* resistance in ohms, C, *c* current in ampères, A, *a* the standard cell and that to be measured.

A is connected with such resistance as is necessary to produce the first fixed deflection, say 20°, and a further resistance, R, is added sufficient to bring the deflection to a second fixed angle, say 10°.

a is now arranged to give 20°; the resistance required for this need not be measured, as it will vary with the internal resistances and has nothing to do with the calculation: further resistance, r, is now added to bring the needle to 10°, then $e = E\frac{r}{R}$ in volts.

This may be simplified by once for all ascertaining the resistance value of 1 volt, and I will exemplify this by an experiment.

A large Daniell with an external resistance of 2·41 ohms, and a total resistance of 2·91, marks 20° on a galvanometer; an extra resistance of 3·11 brings it to 10. Of course it will require the same total resistance with every other Daniell, large or small, to reproduce these deflections, but the external resistances will be different in all cases, for the first deflection; the second extra resistance will be always constant: it is, therefore, a figure representing 1·079 volt on this instrument between these angles, then $1{\cdot}079 : 1 \therefore 3{\cdot}11 :: 2{\cdot}882$. This gives the resistance equivalent to 1 volt, and all future experimental resistances divided by this give the force of the cell under trial—for instance, a Smee cell in full work took 1·35 extra resistance to bring the needle from 20° to 10°. The formula works out thus:—

$$1{\cdot}079 \times \frac{1{\cdot}35}{3{\cdot}11} = {\cdot}468.$$

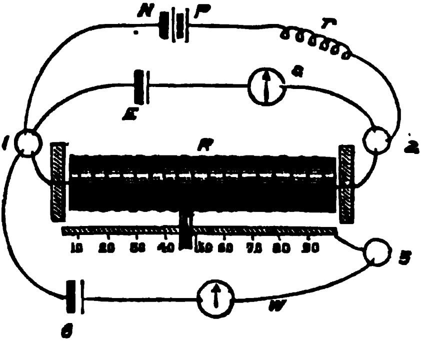
By using the constant obtained at the first experiment, the multiplying by 1·079 is for ever after unnecessary, for $\frac{1{\cdot}35}{2{\cdot}882} = {\cdot}468$. This is the simplest and best plan for obtaining actual working forces at any time.

508. *Clark's Potentiometer* is, perhaps, the best mode of measuring the potential of a cell or battery. It is an instrument resembling Wheatstone's rheostat (p. 237), which by a slight modification may be easily made to serve the purpose.

R is the rheostat, to which an extra binding screw is to be added to provide two circuits, from 1 through the whole wire to 2, and also from 1 through part of the wire to the travelling contact, and thus to 3. Any other apparatus may be used, even a long fine wire fixed over a scale along which the wire shown as connected to 3 may be moved.

E is a standard battery connected through a galvanometer, G, as shown; N P is another battery (both should be constant) connected with a resistance, *r*, which is to be varied till these two batteries exactly balance, and the galvanometer, G, shows no deflection. *e* is the battery to be measured, and is connected as shown (all three negative wires connected together at 1), through a galvanometer to the shifting contact at 3.

FIG. 73.



The effect is that in the wire of the rheostat or potentiometer we have a range of potential from *o* up to that of E, say 1·079 volts, if E is a Daniell: therefore as the shifting contact is moved by revolving the rheostat core, *e* has opposed to it every degree of potential, and a current will pass from or to it until the contact reaches the point of the wire in which the permanent potential is equal to that of *e*, when the galvanometer returns to *o*, and the scale will give the potential of *e* in parts of that of E, and this being known that of *e* is calculated from it. In later forms of the instrument arranged to be used with the cell, § 238, of which the E M F is volt 1·457, the scale is divided to those parts and therefore reads off without calculation.

When the force of *e* is greater than that of E their positions are to be exchanged.

Clark says that by means of a mirror galvanometer and a careful graduation of the instrument it is easy to measure tensions to the ten-thousandth or even hundred-thousandth part of a Daniell cell.

509. *By Condensers.*—The force of cells may be compared by the several charges they can give to a condenser, but this process is one most useful in such technical work as testing

cables, and those employed in such work will have access to those books which enter into this class of subjects more completely than is possible or necessary here.

510. The best of all modes of measuring the difference of potential between any two parts of a circuit or the E M F of a battery, whether working or not, is by means of a delicate electrometer such as the quadrant electrometer of Sir W. Thomson fitted with a replenisher and a gauge (which is itself a disc electrometer), to keep the charge of the movable part perfectly uniform and of known degree: a variation of this charge enables varying forces to be measured, because the deflection is determined by its intensity as well as by the charge derived from the force to be measured, and which is given to the quadrants.

511. *Potential galvanometers* are now made for various practical uses. The difference of potential between two parts of a circuit (as for instance the fall of potential in a lamp, either incandescent or arc, of which the resistance is not easy to measure), is required for the calculation of the energy consumed by the formula E × C which dispenses with the resistance, and enables one instrument fitted to measure large and small currents to take the two required measures.

These instruments simply carry out § 507, substituting a special graduation for the sine or tangent principle: they are simply small current galvanometers of large resistance compared with the resistance of the circuit to which they really act as *shunts*: as therefore this resistance is considered as of no account, the measurement of the potential difference is only approximate; any construction of galvanometer can be used, but as such measures are required in the neighbourhood of large currents and dynamo machines, the instruments ought not to be affected by them. The resistance may be produced by a separate coil or in the wire of the instrument itself: the latter is best, so as to have a large number of turns of wire, with needles whose control is such as to resist the influence.

512. APPARATUS FOR EXPERIMENTS.—As some readers may wish to make experiments on the electromotive force of chemical combinations, such as are examined in this chapter, I will describe the apparatus and process I have, after many trials, found most convenient, the object being to exchange one part for another rapidly, and without confusion or mixture of substances.

It consists of:—

(1) A stand fitted with two binding screws for the wires to go to the galvanometer and resistance, which connections may

thus remain undisturbed for any required time: the screws are connected to two mercury cups into which the wires from the elements dip, thus permitting these to be instantly exchanged.

(2) A U tube of glass or wood cemented, or, what is the same thing, a vessel with a partition descending nearly to the bottom; this contains dilute sulphuric acid or any other liquid which is suitable to the other liquids to be employed at the two elements which it serves to connect.

(3) A number of small porous tubes (3 × 1 inch are suitable) capable of being supported in the U tube at the proper height.

(4) The various metallic plates are each fitted with a wire of such length as to dip into the cups on the stand while the plate is suspended in the porous tube.

This apparatus permits the exchange of each of its constituents in an instant, and in trying various liquids there is little disturbance by endosmose, as the two porous cells containing them are immersed in a bath of intervening liquid. Of course, for experiments with manganese, sulphate of mercury, &c., a porous cell is to be mounted for each substance; and in comparing nitric acid and other oxidizers, &c., a clean carbon must be used with each liquid, but platinum is better, if washed and made red hot. Either a tangent or sine galvanometer, or such an instrument as is described § 511 or § 332, may be used.

513. Energy and Matter.—Some of the general relations of force to matter have been examined, §§ 12 and 155–9; we have now to examine more closely how energy and force assume the form of electric energy or electromotive force. For this purpose we must remember that each atom, and each molecule of matter, involves as part of its inherent nature an amount of energy as definite as of matter, but unlike the matter, not permanent in all changes; it is definite and fixed only for a definite and fixed condition, and for every change a definite change takes place in the amount of fixed energy. We must, therefore, regard energy as possessing twofold conditions.

(1) *Fluctuating*, such as the sensible heat of substances, which enters and leaves them according as they are surrounded by bodies of greater or less temperature, but which does not change either their physical state or chemical properties.

(2) *Fixed*, associated with the matter. Such is what used to be called *latent heat*, now termed, *potential energy;* the best and most definite idea will be obtained of it by treating it, as an amount of energy linked to, or charged upon, the atoms and molecules of matter, and inseparable from them without change of nature or physical state, the mode of charging being the imparting of internal motion.

Each substance requires a definite amount of energy to pass from one physical state to a higher, as from solid to liquid and gaseous; and at each such change a definite amount of energy disappears, becomes charged on the molecules, i. e. is converted into latent heat or potential energy.

Intrinsic or specific energy, § 516, is also fixed and an inherent concomitant of each state of chemical union: every elementary atom has its proper energy, and the importance of this view will be seen when we find that the degree of this energy is really the measure and the cause of the chemical force or *affinities* of this atom. Every chemical action which occurs under the influence of affinity, that is every act of *combination*, is attended with a loss of energy, i. e. the potential energy is set free, and becomes active and sensible in some form, either as heat, or electricity, or motion. On the other hand, every act of decomposition (the reversal of affinity) requires a supply of energy exactly equal in quantity to that set free by the act of combination, and this energy is again charged upon the atoms or molecules, and disappears—without it the change cannot occur.

To make all this really clear, and to attach to our chemical symbols their value in energy as well as matter is at present impossible, as the data are not yet sufficiently ascertained, notwithstanding the labours of Favre and Silbermann, Andrews, and more recently of Thomsen and Berthelot. The latter author has recently published a work on Thermo-chemistry in which the most ample information is contained. As their figures are given in the metric system and often as related only to grammes or pounds, I have reduced the most important of their information, into the equivalent in grains for matter and the foot-pound for energy. I may here remark that I have retained in this chapter the values and calculations thereon as in the first edition, except in some points as to definite relations of weights and measures, which I have altered somewhat to agree with those used by Prof. Everett in his work upon the C.G.S. system of units. The reason I have not changed the values of specific energy for later and possibly more correct ones is that true accuracy cannot be attained as yet: until the real value of the ohm and ampère is ascertained all such calculations must be approximate: when this is done will be the time to aim at exactness, and in another edition many of the figures in this chapter may be somewhat altered, but this will not affect the principles involved.

514. MECHANICAL EQUIVALENT OF HEAT.—As a consequence of the doctrine of conservation of energy, the various forces

(which are forms of energy) are capable of expression either in a single measure or in terms of each other. Experiment has proved this for heat, and shown that a definite quantity of heat is actually transformed into a definite quantity of mechanical work; that is to say, that a pound of water raised in temperature so many degrees Fahr. or raised so many feet against gravity means the same energy expended or stored. What the exact quantity is, is a matter for experiment of a very difficult nature, and therefore the exact value is not really known, and as different values may be found in different books this should be understood. The following is a list of several determinations by different processes in terms of the gramme-metres equivalent to the calory.

Hirn	Friction of water and brass	432
„	Crushing of lead	425
„	Specific heats of air	441·6
Regnault ..	Velocity of sound	437
Clausius ..	General properties of air ..	426
Favre	Electro-magnetism	443
Clausius ..	Heat of current in wire ..	400
Joule	„ „ ..	429·3
„	Friction	423·55

This latter value, which represents 772 foot-lbs. per lb. deg. Fahr. of water, is the one generally accepted at present by engineers. Another value is coming into use, chiefly for arithmetical reasons of the mathematicians: 42 million "ergs" written as 42×10^6 is a handy figure, and this is being adopted: its value in gramme-metres per calory is 427·87, and the foot-lbs. per English heat unit 779·88. The value used in these pages is 772 foot-lbs. and its equivalent in the metric system.

515. RELATIONS OF UNITS.—As different systems of measurement are used in different works, and in most scientific books the metric system is used and may not be understood by all readers, I have worked out Table XVII., p. 325, which, subject to the remarks § 513, shows the mode of converting the values in one system into those of others. I have selected those figures which have proved most useful in my own experience. It should also be remarked that the values here are in slight degree different from others to be found in the work, as in the case of the calory, lines 22 and 23. The cause of this is that the C.G.S. system being based upon definite principles, it is desirable to have the values which are thus theoretically correct: but as neither the ohm nor the ampère, nor in fact several observed data are exact to the C.G.S. system, these other values

may be even more correct in practice, and the differences are not great. The values of the joulad, lines 24, 26–7, on the grain system are here based upon line 23, the theoretical value, while in the body of the work figures may be found based upon line 22, the practical accepted value. The values are as correct as circumstances allow. Different writers call the gramme = 15·438, 15·434, 15·43235 grains, and give the calory unit of heat different values according as it is related to water at 0° or 4° Cent. This name, *calory*, is also given to two values; the original unit and the value always meant in these pages is 1 gramme of water raised 1° Cent., but it is often used to mean 1000 grammes. I have given the logarithms, which are more exact values than the decimals, so that the operations given can be reversed by subtracting instead of adding or by adding the reciprocal of the logarithm (i.e. the log subtracted from 0·0000000), a process often useful also to enable an intricate calculation to be worked out by one final act of addition. The mode in which the figures are obtained, and the plan of using them, will be best seen in an example. Andrews gives the heat of combustion of zinc in oxygen as—

			Log.	
Calories per gramme ..	1330		3·1238516	
Equivalent of zinc	32·6		1·5132176	
Calories per gramme equivalent			4·6370692	= 43358
Ratio of grain equivalent Table XVII., line 9	·198547		$\bar{1}$·2977983	
Foot-lbs. per grain equivalent			3·9348675	= 8607·5
1 lb.	7000 ..	3·8450980		
Zinc	32·6 ..	1·5132176	2·3318804	
Foot-lbs. per pound			6·2667479	= 1,848,195

Owing to the various differences this latter value is sometimes given as low as 1,463,925 per pound.

516. INTRINSIC OR SPECIFIC ENERGY.—These terms are both used by different authors to describe that quantity of energy which is definitely associated in each particular combination of atoms into molecules, § 513 (2). It is the essential agent of chemical relations, and is really the measure of the intensity of *chemical affinity*. In fact this "intrinsic energy" is exactly what the earlier chemists very justly imagined the existence of as necessary to the explanation of the act of combustion; only according to the fashion of that age, they invented a special

form of matter—a fluid—which they called *phlogiston*, to the gain or loss of which they attributed chemical actions. In principle they were more true to nature than the school which succeeded them. However, that affinity is strongest which sets free most heat in calorimetric experiments. Until late years this was not understood, and chemists confined their attention to the material atoms. But we have in *isomeric* bodies the evidence that something besides matter is concerned. There are many pairs of substances which contain exactly the same elementary proportions, but in which the molecule contains double or more of all the atoms in one case than in another. But beyond this there are pairs of substances exactly alike in material constitution, though belonging to different types, § 9: these, however, differ in intrinsic energy, and if equal weights are burned they do not give off equal heat. A great deal of work has been done of late years in this direction by Julius Thomsen and Berthelot, § 513, and the latter has based upon the facts of intrinsic energy a general law of chemical affinity, which he calls the law of *maximum work*, viz. "*All chemical action not due to external energy tends to the production of the body or bodies which set free the greatest heat.*" It will be seen that this is the counterpart of the general law of electrolytic action first explained in the first edition of this work, that those substances are set free by the electric current which *absorb the least quantity of energy.*

We have now to study the mode in which the transfers of intrinsic energy, which is *potential* in the molecules of matter, result in chemical and electrical effects when it becomes *kinetic.*

517. COMBUSTION.—The act of combustion or burning is a most familiar instance of chemical combination, while it is the complete illustration of the potential, latent, intrinsic energy, becoming active or kinetic, and taking the form of heat. At present we may consider it as simply combination, the union, under the influence of chemical attraction, of atoms of carbon, or hydrogen, &c., and atoms of oxygen. There really is also a decomposition of the molecules of these bodies, but that we are not now in a position to estimate. Now, as it is a fundamental maxim that we can create neither matter nor force, and as this action gives us an available free force in the form of heat—where does this force come from? Evidently from the atoms entering into union.

$C+O_2=CO_2$ is the symbol of burning carbon, producing carbonic acid (or more properly anhydride), and $H_2+O=H_2O$ hydrogen burning into water, but these symbols give us no information as to the source of the force. It is, however, evident that before combination there was some force present tending to cause union, which we may call affinity, and that when the union is effected, the resulting substance must have within it less combined energy than its components had before, because the act of union has set force free in the form of heat. This is usually treated as a mere incidental consequence of the affinity; however, it bears an exact ratio to the chemical force, and may be made to give meaning to the old diagrams of elective affinity; by fixing attention upon it, as the "intrinsic energy," capable of exact estimation, instead of the vague "affinity," we shall better understand the facts. Thus, using the equivalent notation, the burning of carbon is

$$\left.\begin{array}{ccccc} C & + & O & = & CO \\ 6 & & 8 & & 14 \end{array}\right\} + 2946 \text{ foot-lbs.}$$

$$\left.\begin{array}{ccccc} C & + & O_2 & = & CO_2 \\ 6 & & 16 & & 22 \end{array}\right\} + 9624 \text{ foot-lbs.}$$

Here the energy set free by the act of combustion is expressed in foot-lbs.; it is the "intrinsic energy," the measure of the force which holds together the atoms composing carbonic oxide, CO, and carbonic acid, CO_2; not wholly so, however, as the great difference between the two figures is due to the fact that a large portion of the energy of the first atom of oxygen is rendered latent in converting the solid carbon into a gas. We cannot be sure that all of the four centres or valencies of carbon, § 6, have attached to them equal specific energy, or we might be able to calculate the force from that given by complete combustion, but in examining actions under the influence of electricity, light will be thrown on this.

518. SALTS.—Combustion or oxidation is only one step in chemical combination, for almost all the substances used in electricity are salts, this term really including acids. The older view of salts, Berzelius's electro-chemical theory, supposed the first step to be oxidation, forming substances which were either acids or bases, according as the element was placed in the electric order, and partly, also, according to the number of oxygen atoms combined, and these two bodies, preserving their original electric relations, combined to form salts. Although this theory is abandoned, it has still, so far a real basis of truth, that the chemical attractions of the elements do in great degree correspond with this arrangement, which so far survives in the new chemistry that the old electro-negatives are still called chlorous or acid radicals, and electro-positives basylous radicals.

Chemical considerations, and especially the behaviour of acids and salts under the action of the galvanic current, led to the adoption of the binary theory, which treats them as composed direct of two radicals, of which the acid, or chlorous one, is a compound containing the whole of the oxygen, while the basyle is an element or a compound having properties analogous to those of elements. On this view the formulæ of sulphates are

$$\left.\begin{matrix}H_2,SO_4\\Zn,SO_4\\K_2,SO_4\end{matrix}\right\}\text{ instead of }\left\{\begin{matrix}H_2O,SO_3\\ZnO,SO_3\\K_2O,SO_3\end{matrix}\right.$$

The ordinary acid being a salt of hydrogen, which is simply displaced by the other atoms possessed of higher "specific energy." This theory accords thoroughly with all the facts of electrolysis, and is that to which belong all the formulæ used in these pages. The older view of salts has, however, a present use in calculating the specific energy of acids and salts.

Returning to the constitution of salts on the old theory: SO_3 four highly negative atoms unite to form a strong acid, sulphuric (now called sulphuric anhydride); hydrogen as H_2O forms a weak base—water; while ZnO forms a stronger; and potassium, K_2O, the strongest base. By combining again, $SO_3 + H_2O$ forms ordinary sulphuric acid, from which the stronger bases can displace the water, forming in turn SO_3ZnO, and SO_3K_2O, sulphates of zinc and potassium.

519. INTRINSIC ENERGY OF ELEMENTS.—The foregoing principles may now be applied by aid of Table XIII., p. 319, in which I have collected the most important information as to the principal elements employed in electricity. Cols. I., II., and III., are the names, symbols, and atomic weights on the new notation, § 11, now generally adopted; IV. the old chemical equivalent, which is also the weight taken in grains, to which Columns VII. and VIII. refer; V. is the valency, § 6; VI. shows the weight corresponding to one unit of electrical current, or quantity, the chemic, § 159, varying in some instances where two classes of salts are formed; VII. is the energy of union with oxygen; and VIII. that with chlorine, of the equivalent in grains, Column IV. These two columns are the specific energies, § 516, of these chemical combinations. In some cases two values are given; they are different results obtained by Andrews (the upper row) and by Favre: the same remark applies to the other similar tables. Column IX. is the electric equivalent in grammes of the coulomb, or the ampère per second, as to which see also § 386.

It is commonly stated, on the authority of Faraday's early experiments, that electricity, passing through several solutions, decomposes them in the *ratio of the several equivalents* (Column IV.). This is not the case; this view of *the equivalent of elec-*

tricity is a delusion based upon the accidental nature of the experiments. The truth, which became manifest only as the modern chemical theories were developed, is shown in Column VI., which shows that the quantity of any element released

TABLE XIII.—ELEMENTS AND THEIR PROPERTIES.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Name.	Symbol.	Atomic weight. New.	Equivalent. Old.	Valency.	Electric Equivalent.	Intrinsic Energy. Foot-lbs. per Grain Equivalent.		Coulomb equivalent in Grammes. H_2O =·000092.
						Oxygen.	Chlorine	
ALUMINIUM	Al	27·5	13·7	3–6	9·17	..	..	·00009370
CARBON ..	C	12·	6·	4	..	2946 9624	as CO as CO_2	..
CHLORINE ..	Cl	35·5	35·5	1	35·5	..	..	·00036289
COPPER (*ic*)	Cu	63·5	31·75	2	31·75	3802 4345	6036 5861	·00032456
„ CUPREOUS	Cu_2	127·	..	2	63·5	..	..	·00064912
GOLD (*ic*) ..	Au	197·	197·	3	65·7	..	..	·00067126
„ AUROUS ..	..	..	..	1	197·	..	..	·00201378
HYDROGEN	H	1·	1·	1	1·	6726 6841	4802 4721	·00001022
IRON (*ous*) ..	Fe	56·	28·	2	28·	6565 7510	6491 9857	·00028622
„ FERRIC ..	Fe_2	112·	..	6	..	..	..	..
LEAD	Pb	207·	103·5	2	103·5	.. 5494	.. 8880	·00105800
MANGANESE	Mn	55·	27·5	2–6	..	..	..	..
MERCURY (*ic*)	Hg	200·	100·	2	100·	.. ..	5793 ..	·00102222
„ MERCUROUS	Hg	..	..	1	200·	..	..	·00204444
NICKEL ..	Ni	59·	29·5	2	29·5	..	..	·00031155
NITROGEN ..	N	14·	14·	3	4·7	..	..	·00004884
OXYGEN ..	O	16·	8·	2	8·	..	..	·00008187
PLATINUM(*ic*)	Pt	197·	98·5	4	49·25	..	..	·00050345
POTASSIUM ..	K	39·	39·	1	39·	.. 15135	20740 19996	·00039867
SILVER ..	Ag	108·	108·	1	108·	.. 1214	.. 6908	·00110400
SODIUM ..	Na	23·	23·	1	23·	.. 14593	.. 18785	·00023511
SULPHUR ..	S	32·	16·	2–6	16·	.. 3526	— —	·00016355
TIN (*ous*) ..	Sn	118·	59·	2	59·	6654	6297	·00060311
„ STANNIC	..	..	..	4	118·	..	..	·00120622
ZINC	Zn	65·2	32·6	2	32·6	8394 8427	10080 9985	·00033324

Hence the coulomb and ampère represent in grain equivalents ·0001578 Log –4·1980458. See also § 386.

depends, not upon its equivalent merely, but upon the state of combination in which it exists, see § 158, that is to say, the valency of the radical it forms.

520. COMBINATION OF RADICALS.—It is evident that whether we call the formula of zinc sulphate, for instance, ZnO,SO_3, or Zn,SO_4, we have the same number of atoms, and, let them have come together how they may, the ultimate result is the same. Now we can actually build up this molecule on the first formula; that is, we can dissolve the oxide of zinc in sulphuric acid, while we cannot form it on the second formula because SO_4, the sulphuric radical or oxy-sulphion, is not capable of separate, uncombined existence. We are thus able to get at the intrinsic energy of the sulphates indirectly, by first ascertaining the heat of oxidation, and then that of solution of the oxide in acid; we thus get the total energy, but only approximately, as we cannot separate from the total the energy due to change of physical state. Table XIV. gives the result in foot-lbs. of the experiments of Andrews and Faure, arranged as in Table XIII.; the considerable differences indicate the difficulties of the process.

TABLE XIV.—ENERGY OF COMBINATION OF OXIDES AND ACIDS.

Oxide of	Sulphuric.	Nitric.	Hydrochloric.
Ammonium	2759 2916	2422 2715	2422 2687
Copper	.. 1533	.. 1271	.. 1274
Iron	.. 2158	.. 1915	.. 1951
Lead	..	1767 1834	.. ..
Potassium	3157 3193	2898 3079	2839 2989
Silver	..	.. 1370	.. ..
Sodium	3216 3139	2779 3034	2918 3003
Zinc	2343 2076	2041 1652	2104 1649

521. In the case of chlorides there is a certain complication, as several actions have to be considered. (1) The actual combination of HCl, which Table XIII. Column VIII. gives as 4721. (2) As this is a gaseous body, its union with water gives further 3258 in forming the actual acid. (3) The heat of

oxidation. (4) The union of acid and oxide. But we have now two products, the salt and water, and therefore the heat of this latter must be deducted to ascertain the energy of the salt itself; and this again includes the heat + or − as the case may be, of the act of solution of the salt.

1. HCl	4721	7979
2. Solution	3258	

The formulæ (equivalent notation) now give the several further stages, taking for examples zinc and sodium:

$$\begin{array}{ccccc} a. & b. & c. & d. & e. \\ \end{array}$$
$$ZnO + HCl = ZnCl + HO.$$
$$NaO + HCl = NaCl + HO.$$

a. XIII. = ZnO	8427	NaO	14593
b. XIV. =	1649		3033
c. Above	7979	HCl	7979
	18055		25605
e. XIII.	6841	HO	6841
d. ZnCl	11214	NaCl	18764
Solution +	1242	—	103
	9972		18867

The last figures agree closely with those of the anhydrous chlorides, of which the zinc gives out heat in dissolving, and the sodium produces cold.

I have in this way calculated the salts in solution, and Column III. Table XV. is the energy thus obtained of the several chlorides, while Column IV. is the energy developed

TABLE XV.—ENERGY OF PROTO-SALTS.

I. Basyl or Metal.	II. Sulphates.		III. Chlorides.		IV. Chlorides by Combustion.
	Ft.-lb. per gr. equivalent.	Equivolts. E M F.	Ft.-lb. per gr. equivalent.	Equivolts. E M F.	
Copper ..	5878·	1·258	6857·	1·467	5861·
Hydrogen ..	8917·	1·919	7979·	1·707	4721·
Iron	9668·	2·069	10599·	2·268	9857·
Zinc	10503·	2·248	11214·	2·400	9985·
Sodium ..	17732·	3·795	18764·	3·996	18785·
Potassium ..	18328·	3·913	19262·	4·121	19996·

by simple combustion in chlorine gas. In this table I have given the energy in equivolts as well as foot-lbs., for use in after calculations. A similar process would, in the case of sulphates, be more accurate than the one employed, if we knew the real energy of formation of SO_3, because, when uniting the acid and base we form water, as well as the salt. I have omitted nitrates, because the reactions vary greatly, and full data are not attainable.

522. Is it not obvious that, by attaching figures like these to chemical symbols, we give them a new meaning and force? if the principle were fully carried out, how clear reactions would become. Why is it that iron and zinc decompose sulphuric acid while copper and silver do not? The tables answer us; the intrinsic energy, i.e. the attraction of copper and silver for sulphuric radical SO_4 is less than that of the hydrogen in the proportions shown, while that of iron and zinc is greater. If the deficient energy is supplied by heating, then copper and silver will react upon the acids: for the same reason nascent hydrogen or sulphuretted hydrogen can precipitate the metals above hydrogen in the list, but not those below, in acid solutions. Every chemical reaction is capable of similar measurement, and the day will come when we shall know just as well the mechanical equivalent of energy in such reactions as we now do the mass of matter taking part in them.

523. Substitutions of Bases.—It follows from what we have seen that if, instead of directly combining two radicals, we substitute one for another, the force of the reaction will be equal to the difference between the attractions; and thus, if we exchange radical for radical in a descending series, at each step we get an instalment of energy set free, and it is found that these instalments bear a distinct relation to the electromotive force of batteries so constituted. The action of the Daniell's cell, which serves as a convenient starting-point for measurement, is simply the substitution of zinc for copper in the sulphate, for zinc is dissolved at one plate, and copper is deposited at the other: the specific energy, therefore, is according to the figures of the tables

Sulphate zinc	10503
„ copper	5878
	4625

$$(1{\cdot}079 \times 4673 = 5042)$$

Andrews gives 5450 as the result of his experiments, which represents 1·167 volts as the E M F.

Present knowledge is not sufficiently perfect to enable us to rely much on any of these figures, but it is generally considered that the E M F of this reaction of the Daniell cell is 1·079 volts, and Table XVI., with the preceding ones, will give readers pretty well all the information at present attainable; the upper figures are derived from those given by Andrews in calories per gramme as the result of his experiments; the lower ones I have calculated from Favre's figures in the previous tables, and in the last column I have calculated these forces in volts, as compared with that of the Daniell taken as datum.

TABLE XVI.—FORCE OF DISPLACEMENT OF METALS.

Metals Displaced.	Metals Substituted.			Calculated in Volts.
	Lead.	Iron.	Zinc.	Zinc.
Platinum	..	..	17605	3·485
Silver	..	..	9127	1·807
	9389	8454	9414	..
Mercury	..	..	6616	1·290
Copper	1685	3719	5450	1·079
	..	3331	6158	..
Lead	..	..	3743	·741
Hydrogen	..	..	3676	·730
		2827	3662	..

524. ELECTROMOTIVE FORCE AND INTRINSIC ENERGY.—Having now, as far as present knowledge permits, ascertained the energy of the various reactions employed in electricity, we have to discover how this energy is changed into an electric current, and to do this we must first ascertain the value in foot-lbs. represented by the volt—the measure of electric potential or pressure. Now it is obvious, that this being a static measure, can no more be expressed by itself in foot-lbs. than can the energy of a ton weight resting on the ground; with the pressure must be united time or motion, as in mechanics.

Just as the attraction of gravity acting through a unit of space furnishes the mechanical unit, the foot-lb., so a unit E M F, a volt, acting through a unit resistance, an ohm, will give us a unit of electric energy if we employ some unit which shall take in it the position which the pound takes in the mechanical unit. This must be something answering in electricity to the idea of "quantity," as the pound represents the analogous idea of *mass* in matter. Such a unit of energy is the joulad, § 390, but the considerations presented § 366 show us that the only proper element for this purpose is that quantity of matter to which Nature herself connects electricity, viz.

$$\frac{\text{Atom}}{\text{Valency}} = \text{electric equivalent.}$$

Any system of weights may of course be used, and when (as must some day be) this conception is adopted as a fundamental scientific principle, of course the gramme or decigramme will be used. At present and here, I of necessity use that weight which is used throughout—the grain equivalent which holds to my *chemic* current the relation which the coulomb holds in the B.A. system to the *ampère* current.

525. An ampère of current is the effect of one volt in a circuit of one ohm during one second, and this current is equal during the same time to 5·68 chemical units, or in ten hours produces 5·68 equivalents of chemical action measured in grains; that is to say, an ampère current maintained for 6338 seconds (or 6338 coulombs) corresponds to a chemic current maintained ten hours, and representing 1 grain equivalent of electric quantity.

526. The energy developed in or absorbed by a circuit is in the ratio of the square of the current, or, what is the same thing, of the electromotive force producing the current. This energy or work may be measured as heat, or in mechanical units; and the value for an ampère under unit conditions is in calories ·24065, which for ten hours gives

Ampère equivalent, calory ·24065 ..	$\bar{1}$·3813859
Calories to foot-lbs., 3·0636	0·4862300
Ten hours = 36000 seconds	4·5563025
Foot-lbs.	4·4239184 = 26544
÷ 5·68	0·7543483
Foot-lbs. per volt equivalent	3·6695701 = 4673

Ten hours divided by 5·68 gives us 6338 seconds as the number of coulombs required to effect one grain equivalent of action. Hence we get by the absolute system

Work of ampère, C.G.S. units, ergs 10^7	7·000,000
C.G.S. unit in foot-lbs.	4·8676563
6338 seconds	3·8019447
Foot-lbs. per 6338 ampères	3·6696010 = 4673

The same result may be obtained in a variety of ways, and each of these calculations (experiments made in figures) furnishes some *data* which, with others similarly obtained, I have transferred to Table XVII. for use in other cases. This result is of supreme importance, for it gives a definite meaning to the volt, which has hitherto been too ideal to grasp.

TABLE XVII.—VALUES AND CONVERSION OF UNITS. § 515.

Name of Unit.	Value in	× Decimal.	+ Logarithm.
1. Metre	Feet	3·28089	0·5159894
2. Ditto (millim. to mils) ..	Inches	39·37042	1·5951706
3. Millimetre square	Circular mils ..	1973·56	3·2952503
4. Gramme	Grains	15·432	1·1884317
5. Gramme-metre	Foot-pounds ..	·007233	¯3·8593253
6. Calory (gm.-deg.-Cent.)	Foot-pounds ..	3·0636	0·4862300
7. Ditto	Gramme-metres	423·55	2·6269047
8. Ditto (mec. equt. = 427·87)	Ergs (see 12) ..	42,000,000	7·6232493
9. Ditto per gramme or ..	Ft.-lbs. per grain	·198547	¯1·2977983
10. „ equivalent ..	Equivolts ditto ..	·0000425	¯5·6281909
11. Centigrade Thermo. (+ 32°)	Fahrenheit	1·8	0·2552725
12. Gravity Force of (*g*) ..	Dynes (say) ..	981·	2·9916690
13. C.G.S. unit the *erg*	Gramme-metre ..	·0010194	¯3·0083310
14. Ditto ditto	Foot-pounds ..	·000007373	¯6·8676563
15. Ampère current	C.G.S. unit ..	10^{-1}	¯1·0000000
16. „ or coulomb equivalent	Gram. × equiv.	·000010222	¯5·0095453
17. „ or coulomb per second	Chemic	5·68	0·7543483
18. Chemic current, 10 hours	Coulombs	6338·	3·8019447
19. Ditto do. Work of (equivolt)	Foot-pounds ..	4673·	3·6696010
20. Joulad (volt-ampère)	Ergs	10^7	7·0000000
21. „ $C^2 \times R$ as work	Foot-pounds ..	·73732	¯1·8676563
22. „ $E \times C$ as heat	Calory	·24065	¯1·3813859
23. „ Theoretical	Ditto, line 8 ..	·23895	¯1·3767507
24. „ × time of grain equt. (18)	1 Equivolt = ft.-lbs.	4673·	3·6696010
25. „ ditto of gramme „	„ Calory system	23287·7	4·3671271
26. „ heats (water + sp. heat)	Grain degree Fahr.	6·6139	0·8204549
27. „ „ copper	ditto, by line 8 ..	65·29	1·8148455
28. „ Sp. Res. cub. cent. ..	R per mil-foot ..	6015350	6·7792609

RATIOS. π = Circumference to diameter 3·14159 Log 0·4971499
„ square and circle of equal diam. 1·2791 0·1049091
„ square area of circle *d*2 × ·7854 „ ¯1·8950909
WEIGHT *of water.* 1 cubic centimetre = 1 gramme „ 0·0000000
„ „ 1 cubic inch .. grains 252·458 „ 2·4021857
„ „ 1 mil-foot .. „ ·0023793 „ ¯3·3764578
„ *of liquids and solids.* × by specific gravity.
„ *of gases and vapours* at 0° Cent. and 760· mm. Bar.
1 cub. dec.-met. = 1 litre or
„ *of Hydrogen* = (1 crith) gramme ·089578 „ −2·9522014
„ of others, multiply by *half the atomic weight.*
WIRES. *mil-foot.* weight in grains (M) ·0211761 „ −2·3258478
Copper „ resistance (pure) at 60° F. (U.) 10·3365 „ 1·0143726
„ „ correction per deg. F. × by deg. 1·00215 „ 0·0009327

527. THE EQUIVOLT.—This is the name I propose for the unit just arrived at, which unites the ideas of *quantity*, *force*, and *energy*, and connects them as a definite value with the atomic theory and notation of chemistry, and as may be seen from its uses, will act as the unit of the correlation of forces. The name is compounded from the "equivalent" as the basis of quantity, and the volt as that of potential.

The equivolt then is—

(1) Energy equivalent to 4673 foot-lbs. exerted upon a polarized chain, each link of which is an "electric equivalent," p. 122, under the strain of 1 volt electromotive force.

(2) The mechanical energy of 1 volt electromotive force exerted under unit conditions through 1 equivalent of chemical action in grains.

(3) The energy absorbed in overcoming each ohm of resistance in a circuit in which a unit of current passes at the normal ampère rate—that is, 1 chemical equivalent in 6338 seconds: 1 equivolt of energy is absorbed in the total resistance, per equivalent of current under any other rate for every volt of electromotive force producing it.

(4) The source of just so many volts electromotive force from any chemical reaction as 1 equivalent of that chemical reaction (measured in grains) will produce equivolts of energy; in this aspect, therefore, the volt and equivolt may be considered as the same thing; thus the total energy of zinc and sulphuric acid is 10,503 foot-lbs. = 2·248 equivolts, and the utmost electromotive force zinc and sulphuric acid can produce is 2·248 volts.

(5) It may also be regarded as a motion (not a velocity) of 1 pound through 4673 feet in 6338 seconds.

528. *The Equivolt as the Unit of Correlation.*—The doctrine of the correlation of forces or equivalent conversion of any one form of energy or "mode of motion" into others, is the grandest and most fruitful of all modern scientific achievements; its value is, however, obscured, and its work greatly limited by the system hitherto employed of using arbitrary units differing for every form of force. Those who have understood the principles involved in the previous sections of this chapter now see that the equivolt supplies the much-needed common unit of measurement for the forces. If adopted into the system of units, it will in all probability have a different actual value from that given here, for the simple reason that I have worked up to it from the unit of current used, viz. the grain equivalent, and have for convenience of readers, used the English measures;

but no definite generally-employed scientific measure will ever be collated to any system of measures so absurd as the English, and therefore it will ultimately be converted to the gramme equivalent and so multiply all the actual values given here by 15·4323, as is done § 559.

That is only a matter of detail; the principle is to express all the different forces in a single unit, to connect that unit with the atomic and equivalent constitution of matter used by Nature, and to make the unit itself one which is readily capable of actual measurement and experiment; all this the equivolt does, and while it facilitates calculations, and will make the different relations of force more readily apparent, it is of course to be converted in a moment to any other unit by multiplying by the proper constants, as given in Table XVII., p. 325.

It should be understood, however, that in the C.G.S. system, the *erg* is to some extent a unit of correlation, as it expresses all forms of energy. But it does not and cannot fulfil the function of the equivolt, because it is a unit of *energy only*, and is not connected to the atom of matter. To make it serve the purpose it would have to be multiplied by a figure which would convert the gramme of mass merely, into the equivalent of hydrogen, and the time under unit E M F as I have done § 559.

529. CONTACT AND CHEMICAL THEORIES.—Ever since the first discovery of that form of electricity which we now call "dynamic," two theories have been maintained as accounting for its production. One school of electricians, following Volta, attributes the origination of electrical currents to a "force" due to *contact;* it is asserted that by the mere coming into contact of the two bodies a disturbance is effected in the supposed normal distribution of electricity, assumed to be a constituent of all bodies, which, extending to neighbouring substances, sets up electric and chemical effects. The other school, following Galvani, has attributed this origin to the *reaction of chemical affinities.* Until quite recently nearly all English electricians have adopted the chemical theory, in the belief that Faraday had clearly demonstrated both the utter baselessness of the contact theory, and also the fact that without chemical action no electricity was developed in the only source of current electricity known till recently—that is to say, in any form of battery.

But in our new source of electricity, the dynamo machine, we do apparently obtain enormous currents of electricity without chemical agency, and this may to some extent explain the revival of the contact theory. But it is very certain that in these machines the source of electricity is in no way "contact," and when we look a little further we find that it may be, in fact, commonly traced to chemical action, because it is derived from the consumption of coal—that is to say, the chemical reaction of oxygen on carbon and hydrogen. The one thing, however, which these machines prove is that electricity is derivable from "energy."

530. The *contact theory* has undergone various changes; at first it was held that the force originated at the point of contact of *the two metals*, say copper and zinc. Faraday demonstrated the production of voltaic electricity when no metals were in contact, and by a number of proofs absolutely demolished the contact theory in this form, and established the chemical theory by proving on the other hand that no electricity was produced except as an *accompaniment of chemical action.* Then the contact theory was modified so as to include the *contact of all heterogeneous substances.* After a time the idea was added, that *contact is the source of the electric force*, but that chemical action was necessary to *maintain the electric current.* Brought into this compass, the question may be defined as being *whether electrical action arises from chemical actions occurring among the bodies present, or whether the chemical action arises because an electrical force is created by the contact of the bodies.* It must be admitted that, so stated, the question seems to be almost one of words, and that there is no practical difference between the two theories, and the molecular theory adopted in these pages really combines the truths of the two others in one harmonious system, for it shows that electric polarization tends to be produced whenever any two heterogeneous substances come into contact.

531. *This contact*, however, is no new mysterious force or "difference of contact potential;" it is the ordinary *chemical* force of affinity, necessarily exerting itself upon *all* its surroundings, whether *within the molecule* constituted by virtue of its action, or *upon the external atoms* brought within its range by this act of contact, which merely means close neighbourhood, allowing force to distribute itself upon the universal law of the inverse square of distances.

Therefore this theory is really the chemical theory and not the contact theory developed, and although it may appear as before remarked, that this is a mere question of words, it is really one of great importance. The point is whether we have the right to invent some new *force*, whenever we want to explain something; or rather, to adopt some sounding word to wrap our ignorance in, and then offer that word as an explanation of facts we do not understand.

532. There is also a wide distinction between the two theories; the contact theory is essentially *atomic*, while the chemical theory is *molecular*. This may sound mysterious at first, and be unmeaning to many, but it involves two widely diverging lines of thought: it will be unmeaning to the purely mathematical mind, which deals with artificial creations and abstractions, whose natural property the contact theory is; it requires the physical training of chemistry to appreciate; but I will explain my meaning.

533. There is a theory of electrolysis which we may call "the dance of the atoms": it is supposed (on this theory) that substances have not the defined construction explained § 158; that dilute sulphuric acid does not consist wholly of molecules of acid and water (H_2SO_4) and (H_2O), but that these molecules are merely temporary formations, and their constituent atoms are perpetually interchanging among themselves like the ladies and gentlemen in the figure known as the "grand chain," or better still, like the gnats one may see on a summer evening flashing here and there and circling for a moment around each other. This strange idea was invented in order to explain why *ions* pass to the two electrodes: these are imagined to exert a force of attraction, each for its oppositely electrified ion, which during its free moments in this "dance" is gradually drawn over.

534. There is *not a particle of evidence to support this theory*, which on the other hand is wholly opposed to all the known laws and facts of chemistry, and especially inconsistent with the known facts of thermo-chemistry. But it just suits the mathematician, as distinguished from the physicist, because he seeks to isolate every idea and fraction of an idea or property, and ticket it with a symbol which he then deals with as a kind of individuality or "person."

But the chemical mind, trained perhaps rather too much in the opposite direction of concrete bodies, treats the combination of the atoms in a molecule as a rigid, definite union; to the chemist this molecular unity is a true marriage, rather than the promiscuous intercourse of this other theory (or at all events as a partnership for the set, to return to the "dance" analogy): he is shocked at the idea of any dissolution of the bonds of chemical affinity, except in the form of a higher affinity, a stronger force which like death breaks the original union only because it removes the two parties to it to new and distinct spheres.

Thus it is that the *contact* theory is related to the *atomic* forces, while the *chemical* theory is related to the *molecular* forces.

535. An experiment of Sir W. Thomson's is constantly quoted as proving the existence of "contact potential": it is a modification of the quadrant electrometer: in this instrument four plates of metal, constituting a true level circle, are connected together in opposite pairs, each of which can be charged from the two poles of any source of electricity; over this plane, or between two such planes, forming an inclosing cell, exactly over the dividing line, is suspended a very light plate of aluminium (of a dumb-bell shape so as to avoid points), which is connected by a wire hanging from its middle to a mercury cup (or to the sulphuric acid inclosed in a Leyden jar to which it serves as both a coating, and an absorbent of moisture) through which it is strongly charged + or −: now if there is the smallest difference of electrification in the opposite pairs of quadrants, this plate is drawn over to the side of those electrified oppositely to itself, to an extent depending on the forces at work, and on the strength of the resistance, which is usually a bifilar suspension. Now if two half rings of different metals replace the quadrants, and the plate is formed so as to lie over only one of the divisions, we have exactly the same conditions; if any "contact force" exist between the two metals, the needle remains at rest when they are separated, and moves when contact is made between them at the opposite ends of the half rings; this is exactly what happens whenever wires attached to the bars are made to touch. Here it may be remarked that this is precisely the same thing as making the metals themselves touch, *no matter what the material of the wires may be:* both in this case and in thermo-electricity it is only the terminal metals which affect the result, because any intermediate junctions neutralize each other.

536. This experiment *proves the chemical theory*. Mr. J. Brown of Belfast repeated the experiment and proved that the difference of potential set up varied in degree, *varied in direction*, according to the nature of the atmosphere bathing the open junction of the metals: the divided ring of two metals with the space between them constitute a pure galvanic cell, in which the relation of the *metals to each other* plays, if any, the most insignificant part, while their relation to *the gas to which they are exposed*, the chemical action set up, is the whole cause and measure of the effect. Exactly what Mr. Fleming, § 245, proved for the liquid galvanic batteries, Mr. Brown proved for this so-called static action, for he showed that the same metals which deflect the index one way in presence of air, deflect it the other way in presence of sulphuretted hydrogen.

537. We may put the facts into the form of a law. *Wherever*

there is free energy present (as heat in thermo-electricity) or *wherever there is potential energy seeking to become free* (as where chemical affinities can come into play) *in presence of differential molecular structures or conditions, there energy takes the form of electric potential.*

The quantity of energy associated with any molecular conditions, or capable of action on the definite molecular chain, is the measure of the degree of electric potential due to the particular conditions. This is what is embodied in my equivolt, § 427, and it is known and admitted even by those who maintain the contact theory.

538. The same law applies to the generation of electromotive force in dynamo machines: it depends upon the energy applied to moving the wires across a magnetic field, in which they are compelled to undergo molecular stresses.

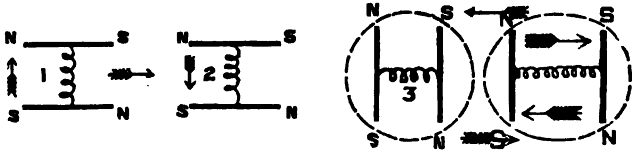
539. Even the difference of temperature of two parts of the same solution will set up E M F: so will the act of solution, which itself generates either + or − heats, § 521; what is the same thing, a dilute and concentrated solution set up E M F at their junction, and in all cases this action is dependent on the direction in which heat passes. In all such cases we find E M F means transmission and change of form of energy, and we may now study the mechanism of the operation.

540. TRANSMUTATION OF ENERGY.—Admitting the existence of atoms and molecules as described (§§ 9 and 158), and the possession by them of mutually attractive powers varying in degree with their nature, it becomes self-evident that as soon as any two different substances come within the range of their mutual attractions, or in contact, they must exert a disturbing action on the arrangement of each other's constituent particles: those atoms in the two bodies which have the greatest attraction for each other will necessarily turn towards each other, and weaken if they do not altogether overcome the attractions which hold them in their original arrangement: the disturbance thus caused is necessarily propagated to the contiguous molecules; hence is produced a consecutive orderly arrangement called *polarization*, tending to complete a closed chain or circuit, owing to the action of the partially released (or as is often, but erroneously stated, repelled) atoms seeking fresh partners or points of union.

541. GALVANIC CIRCUIT.—We may find an illustration in magnetism. We may regard the atom as a small magnetic needle, the molecule, as two such needles mounted on a stem with their poles opposed, forming an astatic system in which the attractions of the several poles satisfy each other; now, this needle

being suspended freely, will be indifferent as to position, but if we bring a magnet near, the existing internal equilibrium is deranged, and the astatic needle will place itself in some position due to the external influence; the same will occur if we bring a second astatic or combined system near the first (they being capable of free motion in any direction)—they will arrange themselves as is represented by Fig. 74.

FIG. 74.



1 and 2 represent molecules held together thus by the forces of polar attraction of the atoms, represented by spiral springs. When two such molecules approach, part of their forces act externally and hold the molecules together, though with a force less powerful than the internal affinity. 3 and 4 convey the same idea more fully; in 3 the internal attraction is shown strong; in 4 it is weakened by part of the attractions being directed externally to the nearest or most attracted of the atoms of the approaching molecule. This is the action described throughout this work as *electric polarization* to which the actions of electricity are chiefly due.

542. We may imagine a line of equidistant supports carrying magnetic needles, which can therefore turn on their axes but not change place.

N S   N S   N S   N S   S
+ −   + −   + −   + −   +

Such a system would arrange itself in polar order, and on the presenting of a S Pole (as S at the end of the row), each magnet would in turn revolve and transmit this motion along the line, or if the terminal magnet were forcibly moved a similar action would occur, and by it mechanical energy would be transmitted, losing itself partly on the way by friction; the more distant magnets would also have less effort exerted upon them, under conditions analogous to the fall of potential in a conductor, § 401.

543. A more mechanical form of the same idea consists of a row of wheels working into each other and all moved by energy imparted to the first one, which energy is transmitted along the

row, each wheel moving on its axis without change of place. It will be seen that this conveys the two ideas of "quantity" and of work just as completely as does the actual transmission of a material bulk of water in a pipe: each single rotation of the wheels is a measure of quantity as perfect as is the motion of a foot of water, and the energy transmitted will be as the square of the number of rotations in a given time. Here then we have, as in electricity, conditions corresponding to the number of turns (quantity) and the pressure applied (E M F), resulting in energy as C × E.

544. POLARIZATION BY POSITIVE METAL.—These ideas are readily transferred to the atoms and molecules of matter, for there is very great reason to believe that every atom is endowed with a species of polarity similar to that of the single needle. A piece of zinc is immersed in sulphuric acid and the molecules in contact instantly arrange themselves thus:

$$\overbrace{\underset{-}{\text{Zn.}}\ \underset{+}{\text{Zn.}}} \qquad \overbrace{\underset{-}{SO_4,}\ \underset{+}{H_2}}$$

one of the atoms of zinc attracting the sulphuric radical SO_4 and weakening the previous internal attraction of this for the hydrogen which, with the second atom of the zinc molecule, similarly exerting external force, acts in turn upon other molecules, till a complete chain is formed through the lines of least resistance; if we continue the formulæ through the action of a Daniell's cell, that is, through sulphate of copper and a wire, it is easily traced.

$$-\ \rlap{\overbrace{\phantom{\text{Zn.}\ \text{Zn.}}}}\text{Zn.}\ \underbrace{\text{Zn.}\ \ \rlap{\overbrace{}}SO_4}\ \underbrace{H_2.\ \ \rlap{\overbrace{\phantom{SO_4\ \text{Cu.}}}}SO_4}\ \underbrace{\text{Cu.}\ \ \rlap{\overbrace{\phantom{\text{Cu.}\ \text{Cu.}}}}\text{Cu.}}\ \text{Cu.}\ +$$

The upper brackets show the original molecules, the lower ones the new attractions exerted and new molecules ultimately formed; the diagram thus shows one atom of zinc removed from one plate and one atom of copper deposited on the other, while the free atoms of zinc and copper propagate the polarization through the connecting wire. A single molecular action is shown here for simplicity, but the full effect can be traced out only in a number of such chains parallel and completed. At present we only seek to examine, not the complete action, but the forces engaged in the action of one molecular chain, and the diagram shows it to be the intrinsic energy given up by zinc combining with sulphuric radical, less that absorbed in separating copper from the same radical; energy which appears as heat in ordinary circumstances, as electricity when the polar chain can be formed; in this latter case disruptive action occurs under a degree of force which would not permit direct chemical reactions; in fact, the best practical electromotors are of this class, where the chemical affinity produces, not disruption, but only tendency to it, i. e. polarization, the actual disruption and complete chemical reaction only occurring when the chain, being completed, allows the force to be distributed along it. This, as a fact, is already generally understood, but the process by which it takes place is not, and yet more, the electromotive force is generally set down as holding some direct and simple relation to the intrinsic energy or chemical affinity alone, which is not really the case.

545. ACTIONS AT NEGATIVE PLATE.—We have seen, § 520, that the total force possibly to be obtained from the equivalent of zinc sulphate is 10,503 foot-lbs., or, the volt being 4673 foot-lbs., we may say that the gross electromotive force of zinc is 2·248 volts, less deductions to be now ascertained. (1) There is the energy absorbed by the substance set free—copper in the Daniell; nitrous gases in the Grove and Bunsen, chromic alum in the bichromate (some of these may be simplified by regarding the process as the liberating of oxygen from prior combination), and most serious of all, hydrogen in the single acid cells. (2) There is the effect of the negative plate itself, and this has hitherto been generally overlooked, although it is well known that the electromotive force of a cell varies with the nature of the negative plate. The theory now under consideration will tell us why. We have seen the zinc polarizing the liquid, but on the same principles every metal would attract the acid radical and tend to produce polarization. Hence the force of polarization produced on the chain is the difference between the two attractions of the metals; this means a struggle between the two metals for the possession of the sulphuric radical, and only the balance of the greater force is available to eject, say the hydrogen, and having done this at an expenditure of 6841 foot-lbs. the residue is all that remains to develop into electromotive force, and ultimately into work, and into heat distributed according to the well-known laws of the ratio of the resistance. The total possible force of a Smee or similar cell is therefore—

Total force of zinc	foot-lbs.	10503	=	volts	2·248
Absorbed by hydrogen ..	„	6841		„	1·464
		= 3662		„	·784

and from this has to be deducted the counter effect of the negative or collecting plate.

546. Here we have the explanation of the rapid failure of power of the single acid cells, such as the Smee, § 121. The E M F tested in such a way as to prevent its working, as by condensers or against a very high resistance, is much larger than this. Clark gives it as 1·098 and as only ·487 when working; the difference is probably the energy absorbed in rendering hydrogen gaseous; for under the first condition (high resistance and very small current) the hydrogen set free does not actually become a gas, it either forms a liquid (metal) film on the plate, or enters into a partial union with it, or is dissolved in the liquids, and the force which would be required to gasify the hydrogen is, therefore, available for electromotive force.

547. In estimating the counter force of the negative plate we require some starting-point to fix an actual value on what is otherwise only relative, and carbon offers a material whose counter force is so small that in the general uncertainty of the figures at present available, we may safely count it as nothing, because, although a conductor like the metals, unlike the metals it has no power to replace hydrogen as a base, or to form salts with acid radicals; hence it is that, properly treated, carbon gives the highest attainable force, and that we may assume, without much risk of error, that the force it gives is the force of the + metal, less only that of the substance set free at the – plate. This applies, however, only to nitric acid and similar cells, on account of the great capacity carbon possesses, like platinum, of condensing hydrogen upon its surface.

Taking the value of the nitric acid cells as given by Clark, Table XVIII., and expressing all the forces and actions in the equivolt, we obtain, as a starting-point, the force absorbed in decomposing nitric acid.

Total force of zinc	volts	2·248
Carbon in Bunsen cell	„	1·964
Force absorbed by nitric acid ..	„	·284

In the Grove cell, all the conditions being the same except that platinum replaces carbon, we have

Force of carbon	1·964
„ platinum	1·956
Counter force of platinum	·008

TABLE XVIII.—ELECTROMOTIVE FORCE OF CELLS IN VOLTS.

Name.	Positive Cell.		Negative Cell.		Authority.		
	Metal.	Liquid.	Metal.	Liquid.	My Experiments.	Clark and Sabine.	De la Rive.
1. Total force ..	Zinc	Sulphuric acid 1–12	..	..	2·248	..	..
2. Smee	„	„	Platinized silver	Dilute acid	1·107 ·508	1·098 ·482	·541
3. Wollaston	„	„	Copper	„	·861 ·270	·886	·719 ·536
4. Bunsen	„	„	Carbon	Nitric acid: fuming	See Table XIX.	1·964	..
5. „	„	„	„	„ specific gravity 1·38		1·888	..
6. Grove's	„	„	Platinum	„ fuming		1·956	..
7. „	„	„	„	„ specific gravity 1·33		1·809	..
8. Bichromate ..	„	„	Carbon	100 water, 12 bichromate, 25 acid	1·905	2·028	..
9. Slater's	Iron	Spent solution	„	Nitrate of soda and sulphuric acid	1·096	..	..
10. Marie Davy ..	Zinc	Acid 1–12	„	Sulphate of mercury	1·542	1·524	..
11. Leclanché	„	Sal-ammoniac	Carbon with manganese peroxide	Sal-ammoniac	1·561	1·481	1·942
12. „	„	Common salt	„	Salt	1·493	..	..
13. Daniell	„	Sulphuric acid 1–4	Copper	Sulphate of copper	1·079	1·079	1·079
14. „ telegraph	„	1–12	„	„	..	·978	..
15. „	„	„	„	Nitrate of copper	..	1·000	..
16. Silver chloride ..	..	..	Silver	Zinc chloride	..	1·195	..
17. Lead	..	..	..	..	..	·578	..
18. „ sulphate ..	Zinc	Acid 1–12	Copper and lead	Sulphate of lead in acid	·550	..	..
19. „ peroxide ..	„	..	..	..	..	..	2·446
20. Grove's gas ..	Platinum	Hydrogen	Platinum	Oxygen	1·5	..	2·518
21. Chromate of lime	Zinc	Dilute acid	Carbon	Calcium chromate	2·070	..	..

These examples show the processes employed in calculating the annexed tables.*

548. ELECTROMOTIVE FORCE OF CELLS.—Table XVIII. is compiled from various sources, as there is a great difference in the values given by different authorities. My own determinations, made for the calculations now being considered, were made with a sine galvanometer through a resistance of 1500 ohms, and with the apparatus described § 512. They only claim approximate accuracy, but answer the purposes for which they are used.

549. Table XIX. shows the electromotive force of Grove's cell under different conditions; it is derived from Poggendorf, and is very instructive. The different force given by the acids in different degrees of dilution well illustrates the mode of conversion of specific energy into electric force. As we mix the acid with water it develops heat, and this means loss of potential energy, therefore a diminished amount available for use; for the same reason heating the liquids increases the electromotive force. Still my own experiments do not show that this source of force produces anything like the effect shown in lines 11 and 12 of Table XVIII., on the authority of Clark and Sabine; I find that the dilution of the excitant sulphuric acid affects mainly the resistance rather than the E M F.

TABLE XIX.—FORCE OF GROVE'S CELL.

Zinc in Sulphuric Acid.	Platinum in Nitric Acid.	Force.
Specific gravity 1·136	Concentrated	1·955
" " 1·136	Specific gravity 1·33	1·809
" " 1·060	" " 1·33	1·730
" " 1·136	" " 1·19	1·681
" " 1·060	" " 1·19	1·631
Sulphate of zinc ..	" " 1·33	1·673
Common salt	" " 1·33	1·905

---

* There are peculiarities hitherto unnoticed in the behaviour of carbon and platinum as negatives. In some experiments I have used two plates of the same size in different reagents. In dilute acids and in chromic acid I found the E M F with carbon one-sixth greater than with platinum. But when the same plates were used in nitric acid, the platinum gave very slightly the greater force. This would indicate a source of the different results by different experimenters: the carbon is known to vary in quality and so does platinum, and besides this there is probably a different relation with each variation of quality, to the acid radicals of different excitants.

550. I have found in all cases, as shown in the last line, that solution of salt in contact with acids gives a higher electromotive force than sulphuric acid does, this being due to the reaction of the two liquids upon each other, which comes in aid of the zinc. It will, however, give higher *current* only when the external resistance is large, as its own greater resistance counterbalances the extra force it generates. A glance at Table XV. will explain this, as Col. III. shows that the force of chlorides in solution is greater than that of sulphates except in the case of the acids themselves: the consequence is that sulphuric acid acts upon salt, the chloride of sodium, and metallic chlorides are produced together with sulphate of soda, and this extra force is added to that of the circuit, as it is in the same direction. For similar reasons HCl gives higher E M F than H_2SO_4 as stated §§ 165, 206, and 211.

551. Table XX. contains my own experiments on the nitric acid and similar cells, arranged to show both the effect of different oxidizing agents, and also the effect of different metals as positives.

TABLE XX.—FORCES OF ELECTROMOTORS.

I.	II.	III.	IV.	V.
Negative Cell.	Positive Cell.	Electromotive Force.	Total Force of Positive.	Loss by Reaction.
Platinum.	Sulphuric acid 1 to 10 water.			
Nitric acid, sp. g. 1·324	Zinc	1·761	2·248	·487
"	Iron	1·184	1·671	"
"	Copper	·786	1·273	"
"	Silver	·678	1·165	"
Nitrate of soda and sulphuric acid	Zinc	1·540	..	·708
"	Iron	1·096	..	..
Bichromate of potash ..	Zinc	1·905	..	·343

552. FORCE OF POSITIVE METALS.—From the force given by each combination in Table XX., and using the force of zinc already obtained by calculation from Favre's experiments as the starting-point, the value of other metals is readily arrived at. Taking 2·248 volts or equivolts as the total value of zinc, the actual force generated under any given conditions gives the loss, or force absorbed by those conditions. In the Grove we have 2·248 − 1·761 = ·487; all the conditions,

except the positive metal, remaining unchanged, this is a constant loss, and by adding it to the actual force each metal yields, we evidently obtain the total force that metal can generate. I give in Table XXI. the results of several such processes, and also the value derived from Favre's figures of the sulphates.

TABLE XXI.—FORCE OF POSITIVE METALS.

Single Cell.	Zinc.	Iron.	Copper.	Silver.
Table XXIII., Col. II.	2·248	1·723	1·280	1·174
Daniell's	,,	1·702	..	..
Grove's, XX., Col. IV...	,,	1·671	1·273	1·165
Favre, XV.	,,	2·069	1·258	..

These figures agree among themselves more closely than those given by different authorities for the same experiments; but iron presents an anomaly, owing, probably, to its capacity for forming two sets of salts. However, while Favre's figures make its value 2·069, Andrews' give it as 1·888, so there is obviously room for further information.

553. COUNTER FORCE OF NEGATIVES.—It was pointed out in § 545, that while the chemical action at the positive metal is the source of the electromotive force, there are two actions at the negative plate which diminish or absorb part of this force; the first of these is the opposing power of the negative plate itself, which we may call the counter force of the negative. This can be ascertained, like the positive force, by keeping all conditions constant except the negative plate. Table XXII. gives the forces produced by both sets of changes at one view.

TABLE XXII.—FORCE OF METALS IN SULPHURIC ACID.

Negatives.	Positives.			
	Silver.	Copper.	Iron.	Zinc.
Platinum	·293	·399	·842	1·367
Silver	..	·139	·582	1·107
Copper	..	..	·236	·861
Iron	..	..	..	·558

The platinum line and zinc column are the observed figures; the others are calculated from them. The forces are those produced against such resistance as prevents the formation of gas; by deducting ·583 from them we get the force under working conditions (§ 545), though here, again, iron shows a discrepancy, as it would appear that iron and zinc would not produce a working current, though in fact they do.

As the full force of zinc is 2·248, and 1·367 is the highest actual force, we have 2·248 – 1·367 = ·881 as the constant quantity to deduct from the total loss which each negative metal shows in the same way with zinc; thus silver and zinc give 1·107, which, taken from 2·248, leaves 1·141 – ·881 = ·260 as the counter force of silver. In this way Column III. of Table XXIII. is obtained.

I may here remark that platinized silver, though coated with platinum, acts precisely as silver so far as the force is concerned; its value is in throwing off the gas, and so diminishing resistance; and hence it would appear that it is more economical in the long run to use platinized platinum than the cheaper silver always used.

Columns IV. to VII. of Table XXIII. show the net force due to the metals of each combination; that is, deducting the counter effect of the negative plate, but not that of any chemical reaction, which is considered separately in next section. Some writers say that this relation is constant for all liquids, but this is entirely misleading; it is wholly a matter of chemical reactions, and the relations may even be reversed; thus iron is positive to copper in acids, but copper is positive to iron in sulphide of potassium and other liquids. See § 245, p. 166.

The figures in the table are based on sulphuric acid, but are approximately correct for all the ordinary combinations, as may be seen by Table XXI.

TABLE XXIII.—FORCE OF METALS IN VOLTS.

I.	II.	III.	IV.	V.	VI.	VII.
Names.	Total as Positives in Sulphuric Acid.	Counter Force as Negatives.	Force of Positives as opposed to Column I.			
			Zinc.	Iron.	Copper.	Silver
Carbon	0	0	2·248	1·723	1·280	1·174
Platinum ..	(?)	·008	2·240	1·715	1·272	1·166
Silver	1·174	·260	1·988	1·455	1·010	..
Copper	1·280	·506	1·742	1·209	..	..
Iron	1·723	·809	1·439	..	..	..
Zinc	2·248	..	0	..	..	..

554. **Chemical Counter Force at Negative Plate.**—The second deduction from the electromotive force is the chemical action in the liquid in contact with the negative plate. In § 545 the force of setting hydrogen free is set down as 1·464 equivolts; this is an excess, no doubt, for it is the force of combustion of hydrogen, which includes the latent heat of gasification of oxygen; in full work, however, the batteries do really appear to absorb this amount, for the counter force of hydrogen coating the plate makes it up. Taking the force when hydrogen is not actually set free as gas, we may obtain the latent heat or energy of gasification.

Force of Smee observed	1·107
„ silver zinc, Table XXIII.	1·988
Difference = absorbed by hydrogen	·881
Force of combustion of ditto	1·464
Probable latent energy of gases	·583

555. This is the deduction to be made from Table XXIII. to get the working force. By similar processes we can obtain the energy absorbed in each of the different actions, and thus is formed Table XXIV.

Table XXIV.—Energy Absorbed in Negative Reactions.

	Equivolts.
Single cells: pure hydrogen	1·464
„ liquid „	·881
Nitric acid. Fuming	·284
„ Specific gravity 1·38	·360
„ „ 1·33	·430
„ „ 1·32	·479
Nitrate of soda and sulphuric acid	·708
Bichromate of potash	·343
Manganese peroxide	·687
Copper in Daniell	·506

By deducting the proper one of these figures from the proper one in Table XXIII., every information can be obtained as to the proper mode of forming batteries, and much waste of time and money may be saved in testing any idea which occurs as to a probable combination; if the requisite metal or liquid is not in the tables, the first thing to do is to make a simple experiment, and add the result to the proper table. Such a process would at once dispose of many of the crude ideas which suggest themselves to experimenters.

The figures in all these tables refer, of course, to the perfect condition of things, and at first starting; in all cases the changes which occur in action soon reduce the force.

556. It is evident from all these figures that E M F and chemical affinity are manifestations of one natural force. It is in fact acknowledged by all electricians that the electromotive force is expressed by the potential energy of any chemical affinity (even by those who say there is no inter-dependence though both may be related to some third agency). It is a certain fact that in electrolysis the act of breaking up a substance into a simpler condition, such as deoxidation, involves the presence of an E M F which takes no part in the usual formula, which is not active in producing current, that is to say, the formula must be written $E - e$ to account for the actual current produced. This $- e$ is just equal to the positive E which the corresponding reverse act of oxidation will produce. On the other hand it is known that some energy disappears which is not accounted for in the R of the circuit, and this energy again is exactly that corresponding to the chemical union broken up; here then we have the two terms of E and energy connected and equivalent.

557. This is commonly stated in the following manner. The work done in transmitting electricity is as $E \times Q$ (which is simply $E \times C$ in another form, without reckoning time, as $C = Q \div T$), and the same formula applies to doing this against an opposing E M F, as in a decomposition cell. In this case a chemical combination is reversed, of which in most cases the calorific equivalent has been experimentally determined, as in Cols. VII. and VIII. of Table XIII.

Let H represent the heat of combination of 1 gramme of a substance; say, taking Favre's values, hydrogen = 34462 combining with oxygen, and zinc passing to sulphate 1623 calories.

Let A represent the ampère or coulomb equivalent of any substance in grammes, Col. IX., Table XIII., multiplied by 10 to bring it to the C.G.S. unit of current, the coulomb being 10^{-1}. J being the equivalent of the calory in ergs 42×10^6, and the volt being 10^8 absolute units (see § 381), we have

$$E \times Q = Q \times H A J.$$

An arithmetical result of this equation is that removing Q from both sides we have $E = H A J$, which means E M F = Energy. An example will make this plain.

In the case of hydrogen burning, we have

H = calories	34462	Log	4·5373405
A =	·00001022 × 10		$\bar{4}.0095453$
J = 4·2 × 10^7 or	42,000,000		7·6232493
Energy in ergs			8·1701351
1 volt = C.G.S. units 10^8			8·0000000
Volts of E M F due to the union of H and O			0·1701351 = 1·480

In the case of zinc forming sulphate we have,

H = calories	1623	Log	3·2103185
A =	·00033324 × 10		$\bar{3}$·5227571
J = $\frac{4·2 \times 10^7}{10^8}$ as before		=	$\bar{1}$·6232493
			0·3563249 = 2·272

Then 2·272 − 1·480 gives ·792 as the E M F of the combined action of zinc dissolving and giving off hydrogen, values which are closely the same as those given by my plan and the equivolt, § 545.

558. Hence we have this definition, *the E M F corresponding to any chemical action is equal to the product of the equivalent weight of the basic ion, and of the heat of combination of the two ions expressed as C.G.S. units of work:* that is to say, when all the elements are reduced to the absolute expression.

It appears difficult to understand how in the face of such a fact and such an accepted law any one can dispute the statement that E M F is merely a metamorphosis of chemical affinity, and talk about *contact potential* in face of the evidence that both chemical affinity and E M F are forms of energy, correlative, convertible, and expressible by identical figures.

559. EQUIVOLT FOR GRAMME SYSTEM.—The foregoing mode of calculation is used in order to follow the argument and to put the facts in the form adopted by most writers, but there is a much simpler way of doing it, which has the great advantage of leading us up to a natural law, instead of a mere arithmetical expression.

Let *H* be the calories per *gramme equivalent*, in which form the value is usually stated, or which can be at once ascertained from H × A above.

Let *J* be the calories corresponding to ampères 6338 × 15·432 = 97808·5 (the time in seconds during which an ampère current effects 1 gramme equivalent of action), = 23287·7 log 4·3671271.

We now have a figure which is for the gramme equivalent and calory system precisely the same thing as my equivolt is for the grain equivalent and foot-pound system. Thus we have

H hydrogen 1 gramme	34462	Log	4·5373405
J gramme equivolt	23287·7		4·3671271
Volts of E M F due to H and O as before			0·1702134 = 1·480

Small differences in the various values are due to the different mechanical equivalents.

560. In connection with these figures it may be remarked that Dr. Alder Wright has carried out a variety of experiments on the E M F actually developed in connection with the combination of hydrogen and oxygen and found it to be 1·5038 volts, as close an approximation to the value deduced from the theory as can be expected when means of measurement differ so much as may be seen to be the case in connection with the E M F of so definite a combination as that of the Daniell cell, and while both the chemical value of the ampère current and the true mechanical equivalent of heat are as yet not exactly determined.

561. WORK OF HEAT VARIES AS THE SQUARE OF THE CURRENT.—The following formulæ give the heat or work developed in any circuit or any part of it by expressing the various factors in their proper units, E in volts, R in ohms, C in ampères, T is time in seconds, and J is the constant in each case representing, in Table XVII., p. 325, the value of the joulad of work:

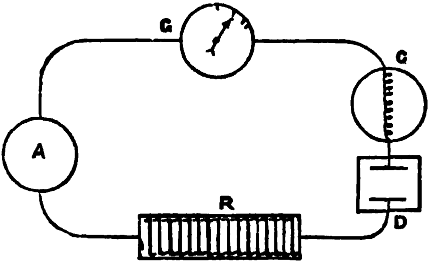
1. $C^2 \times R \times J \times T$.
2. $C \times E \times J \times T$.
3. $\dfrac{E^2 \times J \times T}{R}$.

That is to say, in the same resistance and time, the work of the current varies as the square of the current, or while on the formula $C = \frac{E}{R}$, the current itself under these conditions varies directly in the *ratio of the electromotive force*, the work or heat of the current varies in the *ratio of the square of the electromotive force.*

This is a serious stumbling-block to many (especially when regarding electricity as a fluid) who cannot perceive for what reason the mere doubling the quantity of a fluid passing should endue it with fourfold force; but all the mystery disappears when examined by the light of the molecular theory, as also by the aid of the hydraulic analogies, § 436, &c. Let us, then, study it in a simple experiment measured exactly by the figures we have already obtained.

562. Let us take three exactly similar bichromate cells, A, A^2, A^3, the force of each of which is, per Table XVIII., volts 2·028, the internal resistance taken as ohm 0·2 arranged as in Fig. 75.

Fig. 75.



G is a galvanometer whose resistance we call 0·1, and whose value in ampères is known.

R is a rheostat or resistance instrument for adjusting resistance and current as required.

C is a calorimeter, such as described § 352, the wire of which has a resistance of 1 ohm.

D is a depositing voltameter with two copper plates and a resistance of ohm 0·200.

The functions of these two should be fully understood: D measures current or "quantity," pure and simple; so long as a given current passes, exactly the same weight of copper deposits in the same time, whether 1 or 50 cells be employed, and whether the resistance of D itself be ·2 or 100 ohms. C measures the energy or heating power of the current in a fixed resistance; if its wire be 2 ohms instead of 1, it indicates double work done; but if it be 1 ohm, but the "current" be doubled, then it indicates fourfold work.

563. We wish to obtain through this circuit with one cell an ampère current, what must the resistance be? The formula is $\frac{E}{C} = R \; \frac{2\cdot028}{1} = 2\cdot028.$

The fixed resistance is	G	·100	
	C	1·000	
	D	·200	
			1·300
A, internal resistance			·200
R, rheostat and connections; to be made =			·528
			2·028

Under these conditions a current of 1 ampère passes, and therefore in 6338 seconds 1 equivalent of chemical action takes place throughout the circuit; that is, 32·6 grains of zinc are dissolved in the cell A (independent, of course, of any local action), and in D 31·75 grains of copper are dissolved from one plate and deposited on the other, while in C heat is produced equivalent to 4673 foot-lbs. of energy: that is, enough to heat 1 lb. of water a little over 6° Fahr.

564. We must now assume a few conditions to adjust the experiment to the theory. Let us consider the wire of C as consisting of a single chain of molecules, along which, during the solution of an equivalent of zinc, 4673 impulses or molecular vibrations are transmitted, each impulse being equivalent to 1 foot-lb. of energy for each unit of current generated in the chain; these are the conditions of paragraph 3 of the definition of the equivolt, § 527. These figures, though assumed, exactly express the facts, for it is precisely the same in the end whether one single chain represents each action as 1 foot-lb., or whether a million molecular chains transmit each only one-millionth of a foot-lb.; the total figures are true either way, but the assumption enables us to form a definite conception of the facts, and to deal with them in simple figures.

565. Under these conditions we may deal with the force in a simple Dr. and Cr. account, thus:

Dr.		Equivolts.	Ft.-lbs.
1 equivalent of zinc		2,248	10,503
Cr.	Ohms.	Equivolts.	Ft.-lbs.
Absorbed in deoxidation		·220	1,028
As heat in cell:			
Struggle of polarization, *nil* ..	·000	..	..
Resistance of cell	·200	..	..
Resistance of general circuit, R, D, G	·828	1·028	4,804
Resistance of calorimeter C		1·000	4,673
		2·248	10,505

The value of deoxidation, ·220, is less than that given for the bichromate cell in Table XXIV., but as I am taking the force given by Clark, this necessitates the lessened loss in the reaction; for the present purpose, however, the actual figures are of small consequence so that they are all duly proportioned.

566. We now insert a second cell, A^2, and our E M F becomes 4·056, the internal resistances ·400, and therefore we reduce that of R correspondingly, leaving total resistance the same; then $\frac{4·056}{2·028} = 2$. Our current is now doubled—that is, G marks a current of 2 ampères per second; D deposits 63·5 grains of copper in the equivalent period of 6338 seconds, or twice as much as before; but C marks heat equivalent to 18,692 foot-lbs., or 24·2 heat units, that is, fourfold energy, instead of only double like the rest. Why? There being two units of current there are two equivalents of zinc dissolved *in each* cell. There are two cells, and therefore we have fourfold energy given up by the zinc. But the chain of molecules is unaltered, except that by inserting the second cell we have doubled the strain put upon the chain, making it 4·056 volts instead of 2·028, and therefore each molecular impulse has a force now of 2 foot-lbs.; owing to this doubled energy it overcomes the resistance in half the time, and therefore the current is doubled.

But the consequence of this is that in the time of the experiment we have now 4673 × 2 = 9346 molecular impulses (which represent the "quantity" or current), each effected under a force of 2 foot-lbs., and as resistance means, and is measured as, the effecting each such impulse in the single time, these conditions imply that the work of overcoming resistance in half the time is, for each ohm of resistance, 9346 × 2 = 18,692 foot-lbs.

567. We now state the second set of conditions in a Dr. and Cr. account like the first:

Dr.	Equivolts.		Ft.-lbs.
Cell A, 2 units of zinc	{ 2·248 { 2·248	.. ..	10,503 10,503
Cell A^2, 2 units of zinc	4·496	..	21,006
	8·992	..	42,012

Cr.			Equivolts.	Ft.-lbs.
Deoxidation 4 units at ·220		..	·880	4,112
Absorbed per ohm:—				
In doubling current	= 2·000		..	..
In doubling force	2·000		..	..
	2 × 2 = 4·000		..	..

		Ohms.	Equivolts.	Ft.-lbs.
Resistance of cells ..	·400	..	..	..
Resistance of general circuit	·628	1·028	4·112	19,216
Resistance of C ..	..	1·000	4·000	18,692
		2·028	8·992	42,020

The slight difference in the foot-lbs. is owing to the use of even numbers and neglecting small fractions.

The experiment with three cells would give exactly the same result, except that 9 equivalents of energy per ohm are required to maintain a threefold current, and it is needless to occupy space in working it out in detail.

If in the second case we add an equal extra resistance, and so keep the current at the 1 ampère as in the first case, we get 1 equivalent of zinc consumed in each cell, and the conditions become:

Dr.	Equivolts.
2 equivalents of zinc =	4·496

Cr.		Ohms.	Evlts.	Evlts.
Deoxidation, 2 cells ..		..	..	·440
Resistance:				
Cells		·400	..	..
Circuit	·628	..	..	..
Extra	2·028	2·656	..	3·056
C. Calorimeter		..	..	1·000
				4·496

568. This may be stated in another way, which will exhibit the principle clearly. The units of measure we deal with embrace four elements: (1) mass or quantity moved; (2) space moved through, or the R; (3) time during which motion is produced; (4) the absolute force operating. The final result in any special case, as compared with the unit standard, will vary in the ratio of each and all of these four elements; time, of course, in *inverse* ratio. The electrical measures are, in fact, linked to these several units. In our present experiment—(1) is a unit molecular impulse of 1 lb.; (2) is 4673 ft. (and this also under the condition of unit current represents 1 ohm resistance); (3) is the duration of 1 equivalent unit current, 6338 seconds; (4) is the volt, and in unit conditions links all. We have, therefore, in the first experiment of 1 ampère current, forces as expressed in line A below; in the second, of 2 ampère currents

in same resistance, the conditions are expressed by lines B and C, according as we regard the time or the current as the fixed element:

	1 Current.		2 Ohm.				3 Time.		4 Force.		
A	1	×	1	×			1	×	1	=	1
B	2	×	1	×			1	×	2	=	4
C	1	×	1	×	½	=	2	×	2	=	4

569. From all this it follows that, starting with the normal amount of energy expressed in the units, the energy needed to generate current and the energy absorbed in the circuit or in each ohm of the resistance vary as a fact in the ratio of the square of the current passing; but it is very evident also that the statement that the work of a current varies in the ratio of the square of the current is, after all, only a mathematical expression based for convenience upon a single one of the two varying conditions, as with static electricity, § 71, for the real fact, as shown in the several Dr. and Cr. accounts, is that it varies not as the square, but in the direct ratio of the current, that is, of the number of molecular actions in a given time, but that it also varies in the direct ratio of the force under which these actions occur; it is because these two necessarily vary in exactly the same degree, one being dependent on the other, that the combined effect can be truly represented as due to the square of either one of them. The same principle will be found to underlie every action which varies in the ratio of the square of its apparent cause, examination will always discover a second cause operating *pari passu*, the two linked together and therefore producing a result which can be expressed as the square of either of them.

570. Potential *regarded as energy*. We may now revert naturally to the examination of "electric potential" from the other point of view referred to § 439, that which is involved in its definition as *work*, § 76. All the facts and figures in this chapter show that E M F is equivalent to *energy stored in and applied upon a definite molecular chain*; that "volts" are as "foot-lbs." of energy thus stored; therefore, returning to the table of the "Force of Gravity," p. 263, it follows that potential, that is electrostatic potential, corresponds to Col. VI. potential energy, *head of water*, although its dynamic equivalent, electromotive force, equally measured in volts is best understood by treating it as Col. VIII., which is the *square root* of head of water or potential energy.

571. The reason is that E M F is employed simply to explain

the generation of *current*, which corresponds to *momentum*, these being proportional to the square root of head of water in hydraulics, while electrostatic potential is defined as work or energy, and therefore corresponds to head of water. That each of these views is true and useful in electricity corresponds to the fact that both are true and useful in hydraulics; that both views are capable of expression under one common unit, the volt, is a curious result of their mode of use in Ohm's formulæ.

572. Let us now work out the idea that E, electromotive force or potential, as expressed in the volt, represents the *potential energy stored upon and to be expended within the unit molecular chain:* the links of this chain corresponding to 1 grain equivalent of chemical action.

We have here two distinct quantities to deal with, those referred to §§ 14 and 15, which the reader will do well to examine now.

(1) A quantity of energy *Q*, which is 4673 foot-lbs.

(2) A *quantity so-called* Q, which is treated in different manners by the different schools of electricity, and upon the clear conception of which the comprehension of electrical phenomena depends. It is very commonly called the *quantity of electricity*. It is that which is expressed by the electrostatic unit (§ 55), or by the coulomb (§ 387), which is 3×10^9 electrostatic units. It is also represented by the material quantity which is commonly regarded as associated with the electric quantity as its effect, that is to say, those material values given Col. IX., p. 319.

Here it represents 6338 coulombs, the value corresponding to 1 grain equivalent of chemical action, associated under the unit system with 4673 foot-lbs. of energy.

573. There is no more real mystery about these two quantities in electricity than there is in mechanics, where also they are constantly present; the mystery which surrounds them in the usual mathematical treatment is entirely due to the artificial "electricity" which has been invented by the various theorists. We can examine them and their relations by a modification of the hydraulic analogy of §§ 436 and 437, where we considered electromotive force as related to velocity or current, and as corresponding to the square root of potential energy and of head of water, to which we have now to consider it as directly related.

574. But while, § 437 (*k*), velocity or current is as the *square root of head of water*, the formulæ for working out hydraulic problems are usually based upon *head of water* simply, and the

resistances are reckoned in terms of the "head" necessary to overcome them, which by so much reduces the head effective for generating current. We cannot adopt this process because the mechanical and electric analogy is not perfect, for reasons given § 44: the running water, the falling weight, retain in themselves a portion of the energy derived from the fall, greater in proportion to its rapidity, while in the case of electricity the energy is wholly expended in the current. Most hydraulic formulæ relate really to this residual energy, which has no counterpart in electrical problems; on the other hand, it is because the expenditure of energy *within the circuit*, which is the essential question in electricity, is in some aspects only to be expressed in terms of the square of the other quantity Q of § 572, that Ohm's formulæ, which relate to both quantities, may be treated in such seemingly inconsistent methods as noted §§ 439 and 570.

575. We can, however, deal with the analogy by considering the unit electrical conditions as comparable to those of a column of water 4673 feet in height, with a conducting pipe such as allows the unit quantity (4673 lbs. of water) to flow in 6338 seconds, which is a current of pound ·7373 per second; in this case the quantity and energy are expressible in the same terms of the pound, as a value corresponding to the unit energy of the ampère current, i. e. the joulad, which is ·7373 of the foot-lb.

The same idea will probably be more completely received by many minds in the form of a pound weight suspended by a cord 4673 feet long, and doing work as it descends, in the normal time of 6338 seconds.

576. It will be well to trace the relations out step by step.

(*a*) *Electromotive force* E means a quantity *Q* of potential energy (of which the unit = 1 volt is 4673 foot-lbs.) charged upon a chain of molecules corresponding to a quantity Q, which is, for each link of the chain, 1 grain equivalent of chemical action.

Mechanico-motive force, § 431, will in like manner be represented by the column of water or the weight of § 575.

(*b*) This *potential* energy is in the electrical case, *wholly* converted into *kinetic* energy; but the *rate of conversion* depends upon the conditions under which it takes place.

(*c*) *Rate of conversion* of energy *Q* is proportional to *rate of chemical action* Q; both correspond to the rate of fall of the water or the weight § 575.

(*d*) *Current* is *quantity divided by time*, that is to say, it is rate of conversion or transmission: it is usually considered as the latter only, but it is necessary to extend the idea of the current to energy as well as matter or electricity. Therefore

$$\frac{\mathrm{Q}}{\mathrm{T}} = \mathrm{C} \quad \text{and} \quad \frac{Q}{\mathrm{T}} = C.$$

(*e*) Unit *time* is 6338 seconds, and therefore unit C = $\frac{1}{6338}$ of H hydrogen, and unit $C = \frac{4673}{6338} = \cdot 7373$ foot-lb.

(*f*) We see that in this formula T, time, replaces R, resistance so-called, in the ordinary Ohm's formula; in fact, the statement that current is quantity divided by time, and the statement (*b*) that rate of conversion or transmission depends upon the conditions under which it occurs, are the same thing differently expressed, for time is simply the inverse measure of relative facilities of conversion and transmission: if the facility of transmission is reduced to half, as by halving the area of a conductor, the time of transmission of unit quantity is doubled.

(*g*) *Time* of flow of unit quantity is therefore the measure of conducting capacity, and is the real thing represented by the so-called resistance, the R of Ohm's formulæ, which in § 441 was shown to represent the reciprocal of this capacity. In fact, current is *as conducting capacity*, and it is also (*d*) inversely as "time" or "resistance," whichever expression best suits particular requirements.

(*h*) *Electric resistance*, the R of Ohm's formulæ, represents really *the time during which the unit quantity of potential energy becomes kinetic*, and this under unit conditions of the grain equivalent is 6338 seconds: but this definition is limited to the action of unit E M F.

(*i*) The conducting capacity of any circuit is proportional to the E M F acting upon it, § 443, for this is only another way of stating the fact that current is as the E M F, or that the resistance is alike for all currents. In other words, the actual capacity = the unit × E, and it is the reciprocal of this which, § 441, constitutes the artificial "electric resistance" R, though this is arrived at by methods apparently independent of the variable E M F.

(*k*) To make the definition of (*h*) general, we must in like manner take into account the E M F operating, and then we shall find that R corresponds to T ÷ E, time divided by the E M F, as to unit energy (*i*). But R = T direct when we consider the material quantity or current; that is when $\mathrm{C} \times \mathrm{T} = \mathrm{Q} = 1$. In this case also T is really the unit time 6338 ÷ C, which in (*f*) is shown to correspond to R.

(*l*) The reason of this is evident when we consider that, as regards energy, we are dealing with limited quantities Q and *Q* divided by time T, while Ohm's formula deals, not with a general quantity, but only with the quantities related to a single second.

(*m*) Thus, if we double E we double current C, and therefore halve the time T during which the unit quantity Q (to which we are limiting our consideration) passes. But by doubling E we have doubled the quantity *Q* of energy connected to the material quantity Q, and therefore we have these conditions,

$$\text{As to matter } \frac{2\ \mathrm{E}}{1\ \mathrm{R}} = 2.\mathrm{C} \text{ and Q is } \frac{\mathrm{C}}{2} \times \frac{\mathrm{T}}{\cdot 5} = 1.$$

$$\text{As to energy } \frac{2\ Q}{\cdot 5\ \mathrm{T}} = 4.C \text{ and } Q \text{ is } \frac{C}{4} \times \frac{\mathrm{T}}{\cdot 5} = 2.$$

These are the conditions of (*a*), those of the unit molecular chain corresponding to Q, upon which are charged quantities of energy corresponding to *Q* × E, agreeing also with the laws of energy as corresponding to $\mathrm{C}^2 \times \mathrm{R}$ or C × E.

577. Probably a few examples may make the matter more evident.

Action of Q = Current.	Action of *Q* = Energy.
$\frac{1\text{ Volt}}{1\text{ Ohm}} = 1\text{ Ampère.}\quad \frac{1\ \mathrm{E}}{1\ \mathrm{R}} = 1\ \mathrm{C}.$	$\frac{\text{ft.-lb.}\ \ 4673.}{\text{seconds}\ 6338.} = \cdot 7373\ \ \frac{1\ E}{1\ \mathrm{T}} = 1C = \mathrm{J}.$
$\frac{\mathrm{E}\quad 1}{\mathrm{R}\quad \cdot 5} = \mathrm{C}\ 2.\ \ \frac{\mathrm{J} \times \mathrm{E} \times \mathrm{C}}{\mathrm{J} \times \mathrm{C}^2 \times \mathrm{R}} = \frac{\text{ft.-lbs.}}{1\cdot 479}$	$\frac{\mathrm{E}\ 1. = 4673.}{\mathrm{T}\quad = 3169.} = 1\cdot 479\quad \mathrm{T} = \frac{6338}{\mathrm{C} = 2.}$
$\frac{\mathrm{E}.\ \ 2.}{\mathrm{R}\quad \cdot 5} = 4.\qquad \mathrm{J} \times 2 \times 4 = 5\cdot 899$	$\frac{\mathrm{E}\ 2. = 9346}{\mathrm{T}\quad = 1584} = 5\cdot 899\quad \mathrm{T} = \frac{6338}{\mathrm{C} = 4.}$
$\frac{\mathrm{E}.\ \ \cdot 5}{\mathrm{R}\quad 2.} = \cdot 25\quad \mathrm{J} \times \cdot 5 \times \cdot 25 = \cdot 092165$	$\frac{\mathrm{E}\cdot 5 = 2336}{\mathrm{T}\quad = 25352} = \cdot 092165\ \ \mathrm{T} = \frac{6338}{\cdot 25}$

I will work this last out fully in logarithms.

E. $\cdot 5$ = $\bar{1}\cdot 6989700$		unit time 6338. = $3\cdot 8019447$
R $2.$ = $0\cdot 3010300$		C $\cdot 25$ = $\bar{1}\cdot 3979400$
C $\cdot 25$ = $\bar{1}\cdot 3979400$		T 25352 = $4\cdot 4040047$
J $\cdot 7373$ = $\bar{1}\cdot 8676563$		unit *Q* 4673. = $3\cdot 6696010$
E $\cdot 5$ = $\bar{1}\cdot 6989700$		E $\cdot 5$ = $\bar{1}\cdot 6989700$
$\bar{2}\cdot 9645663$		*E* 2336. = $3\cdot 3685710$
		T 25352 = $4\cdot 4040047$

Energy expended per second = $\cdot 092165$ = $\bar{2}\cdot 9645663$

Showing the potential energy of the E M F converted into kinetic energy in transmitting current.

578. One remarkable result of these views of electric action is, that we can entirely eliminate the ideas of electromotive force and of resistance, replacing them in calculation by "energy at disposal," and "facility for its transformation": we can then arrive at the results of Ohm's formulæ by a calculation based upon unit values of these two elements.

579. For the convenience of comparing processes of thought, let us make the ampère current the starting-point, the term in which we desire to express results.

(*a*) Let C be the current per second of which the ampère is the unit, represented by ·00001022 gramme of hydrogen, or the equivalent of any other substance.

(*b*) Let J be the unit of energy corresponding to that of 1 ampère current during 1 second, under such conditions as we constitute as the unit of "facility of transformation of energy": actually we make J = the joulad, calory ·24, or more exactly Log ‾1·3767503.

(*c*) Let A represent, as in § 441, the unit conductor just referred to, which permits J to be transformed from potential to kinetic energy while generating 1 ampère current; this property is of course dependent upon some specific constitution of the matter in which the transformation is effected, with which we have not now to concern ourselves.

(*d*) A and J are therefore so connected with C, that any two will of necessity define the third, and C and J being defined, A may be fixed by arranging a circuit in which J produces C, and this may be defined as the unit conductor. As this converts the whole of J into heat or kinetic energy, a similar conversion must occur in a succession of such circuits through which C passes, and each must require J of energy to be supplied to it: failing this, a smaller quantity of energy will be distributed over each unit portion, and a smaller current will traverse the series.

(*e*) The value A will increase in the ratio of the number of such unit conductors equally open to the energy, that is parallel circuits: it will diminish in the ratio of the number added to the circuit. Or if we regard the consumption of energy as a resistance, the *true resistance* of § 426, then A will be *inversely* as the number of units of energy J necessary to maintain the current, or unit C with unit E M F.

(*f*) It is obvious that we have here values corresponding to those of the volt and ohm, and of necessity so, because we have started from the ampère, with the intention of making the two sets of ideas run parallel with each other, so as to illustrate the natural truths embodied in them, and evidently the actual values must be the same, whatever theoretical views we may connect to them.

(*g*) Let P be the potential energy of the gramme equivalent of any chemical reaction, generating electric current (expressed, as it commonly is, in calories), multiplied by the ampère equivalent of hydrogen; or the calories per gramme may be used and multiplied by the ampère equivalent of the basic ion entering into the action, as in § 557. For example,

Calories per equivalent hydrogen	·34462	4·5373405
Ampère equivalent „	·00001022	$\bar{5}$·0095453
P = potential energy.		$\bar{1}$·5468858

(*h*) This gives us the potential energy which we have available for charging upon the molecular chain in which it is to be rendered kinetic. This value if divided by J gives us the expression of E M F in volts, as in §§ 557 and 559; J is in fact a unit expression or value of P which needs to be reduced to this unit in order to give results in ampères of current; but J is not a volt of E M F when so employed, but a form of the "equivolt" § 527 reduced to the ampère equivalent instead of the gramme equivalent of § 559, or the grain equivalent of § 526: that is, it expresses energy itself, not the E M F to which the energy is equivalent when the existence of E M F is assumed.

(*i*) Now J × A = C. That is to say, potential energy × by the capacity for transformation = the rate of conversion in the molecular chain in which it occurs, such conversion being effected by a molecular change which we can call a quantity, and measure as current.

580. This mode of considering the subject is exactly parallel with that of § 441, where E × A = C in accordance with the usual system of E M F and conduction.

Of course this process is not proposed as having any importance as to practical use, but it shows that the received formulæ, however useful, are purely artificial; it shows that the conceptions of electromotive force and resistance are mere expressions, not for facts or actual existences, but for *conditions*; and it altogether disposes of the fictitious "contact *force*" by showing that pure energy accounts for all the phenomena which this force was invented to explain.

CHAPTER IX.

ELECTROLYSIS.

581. The name *electrolysis* (breaking up by electricity) is given to the process of transmission of the electric current through liquids, when accompanied by the disruption of the molecules composing the circuit, the constituent radicals of the molecules being set free at the two poles.

The plates in the decomposition cells are called *electrodes* (electric ways): the plate connected to the + pole of the battery, the copper, platinum, or carbon, is the *anode* (way up, as carrying the current out of the battery); the plate connected to the – pole of the battery, the zinc, is the *cathode* (downward way).

The liquid undergoing decomposition is the *electrolyte*. The molecules of an electrolyte break up into two radicals, which are called *ions* (indicating individuality, and in another sense meaning *going*). These radicals or *ions* form the two classes described § 158, and illustrated in Fig. 43, p. 122. Those ions which turn towards the anode are called *anions*; they are electro-negative or acid radicals, such as oxygen, chlorine, SO_4, &c. Those which turn towards the cathode are called *cations*; they are electro-positives or basic radicals, as hydrogen and metals. The same ion may belong at different times to each of these classes, if united to one having a higher individuality in either direction, for there is no direct attraction between the electrodes and the ions themselves, but the relation depends simply upon the temporary polarity they assume in the circuit.

582. *Ions* or radicals may be single atoms, or compounds which act as radicals chemically, and these may even be incapable of actual separate existence, as far as present knowledge goes. HCl is an electrolyte composed of two single atoms; in H_2SO_4 two atoms of hydrogen form one ion and the compound radical SO_4 the other; this radical cannot exist uncombined, so that sulphuric acid is an electrolyte only when in presence of something it can react on, and combine with, such as water, although water itself is not an electrolyte.

Ammonium NH_4 is also a compound ion strongly resembling potassium in its properties; it also cannot exist free, but breaks up into NH_3, ammonia, and H, giving an *apparent* exception to the law of equivalence by producing two free substances, each equivalent to the current producing them; but it must be considered that ammonia is not really a radical, for NH_3 is a complete molecule of the order described § 10 (1) p. 7, and is not capable of replacing H in salts.

583. We must regard the circuit as consisting of chains of molecules; some metallic, as in the plates and conductors; some liquid, as in the cells; and the transmission of electricity as consisting of a motion of each molecule in the chain, accompanied with the breaking in halves of a molecule wherever the current passes from metal to liquid, or *vice versâ*. We shall thus understand why there is equal current, equal quantity of electricity, or equivalent chemical action at every section of the circuit, as stated § 160, p. 123, because there are the same number (or value, as will be seen presently) of molecular actions effected at every part, however the molecules themselves may differ in nature. Each cell is, therefore, a section of the conductor, and each has its own specific resistance just as the wire portion has. But the cells are of two orders in another respect.

(1) Generating cells, in which energy is set free by chemical actions, and becomes electromotive force, setting up the current as explained Chapter VIII., §§ 524–554: these are battery cells and stand for E in formulæ.

(2) Decomposition cells, in which energy is absorbed in doing chemical work. These may be simple resistances, where no ultimate change is made in the solution; such are most electro-metallurgical processes where the same metal is dissolved from the anode as is set free at the cathode. But if any *ions* are actually set free by the current, they tend to recombine and act as a cell of the first order with their electromotive force opposed to that of the battery, and stand as $-e$ in formulæ, as in secondary batteries § 262. The feeblest E M F will send a current through the first of these classes of decomposition cells, but the second class require an E M F greater than that set up by the action itself, or electrolysis cannot take place, for reasons explained, § 599.

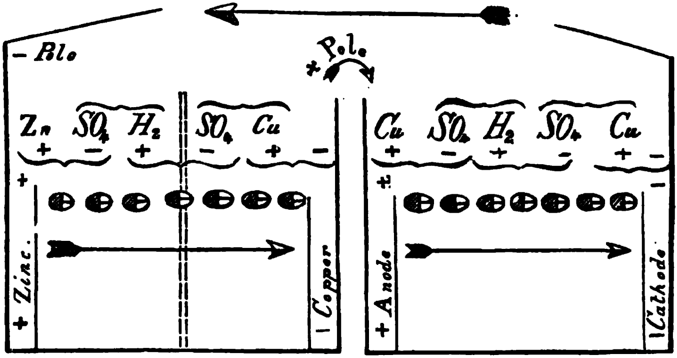
584. Except for this distinction of generating and decomposing cells, all the cells are under the same conditions. In each cell there is a + plate or element, the zinc in the battery cells and the anode in the decomposition cells, and if the latter can unite to the chlorous radical of the electrolyte it dissolves just

as the zinc does in the battery cells. In each cell there is the electrolyte, which gives up its chlorous or − ion at the + plate, and transmits the molecular motion which constitutes the current to the − plate where it also gives up its + ion. The − plate then continues as the + pole or anode to the next cell, and ultimately to the − pole or terminal zinc of the battery to complete the circuit. In fact, each pair of connecting plates in separate cells, acts as though it were a metallic partition separating the two liquids with which the plates are in contact. In such a plate, or conducting partition, one side would be + and the other side −, and the two plates in different cells correspond to these two sides, united by a connecting wire instead of by the mass of metal of a plate itself. It is of the utmost importance to bear in mind this distinction of *plates* or *elements*, related to the liquid within their own cell; and *poles* or *electrodes*, related to another cell and to the direction of the polarity they set up, or the current they transmit, and the student should carefully study the diagram of these actions p. 175. Leaving out of sight the distinction of cells as those setting up and those absorbing energy, that plate in each cell which is + to its own liquid, or the positive *plate* of the cell, is the anode or + electrode of the cell to which it is connected, and completes the circuit from the − plate of this cell. Hence it is that the anode in the decomposition cell represents the zinc in the battery cell, for like the zinc it is + to the liquid, and gives up energy to the liquid (though that energy is derived from the current itself in this cell), and like the zinc it dissolves, if made of materials which can combine with the negative or − radical of the solution. For this reason some prefer to call the anode the *zincode.*

585. Fig. 76 exhibits these relations, in the actions of a Daniell cell and an ordinary coppering arrangement.

It shows the polarization set up in the complete circuit from the zinc in the liquid, with equivalent actions resulting in both cells, the upper brackets showing the original arrangement of liquids, the lower ones the effect of the action. At the + plates to the left in each cell, zinc in the battery, the anode in the decomposition cell, an atom of metal is removed from the plate; the intervening molecules transmit the action, and absorb the ion originally united to the first acid radical; and in each cell, at the end of the chain in contact with the negative plate or cathode, there is set free a positive radical; in this case copper in both cells. This diagram is arranged to furnish several illustrations of the laws of electrolysis, and should be studied in connection with Fig. 43, p. 122, which more fully explains the ideas to be associated with the ellipses in Fig. 76; these represent the molecules and their constituent radicals or ions, expressed also in the chemical formulæ, while the symbols + and – show the classes of radicals, + being the cations, and – the anions; their arrangement exhibits the order of polarity set up, while the arrows show the direction of the current within the cells and in the outer circuit.

FIG. 76.



Battery. *Decomposition.*

586. The laws of electrolysis usually accepted are those of Faraday, who also originated the terms described. These laws are—

I. *No elementary substance can be an electrolyte.*—That is to say, the two ions must be differently composed.

II. *Electrolysis occurs only while the body is in the liquid state.*—This state may be due to either fusion or solution; in the latter case many substances become electrolytes by a *secondary* action, which are not so of themselves.

III. *During electrolysis the components of the electrolyte are resolved into two groups; one group takes a definite direction towards one of the electrodes, the other group takes a course towards the other electrode.*—They turn towards the several electrodes in polar order, but are not attracted or moved towards them by a direct attraction of the polar electrodes. Faraday held that only substances containing single equivalents of each radical could act as electrolytes, but this is now superseded by more general conceptions. See also § 533.

IV. *The amount as well as the direction of electrolysis is definite,* *and is dependent upon the degree of action in the battery, being directly proportional to the quantity of electricity in circulation.*—This law is explained by § 595, which shows that "quantity of electricity" means number of equivalent molecular actions.

V. *Those bodies only are electrolytes which are composed of a conductor and a non-conductor.*—This addition of Miller's is useful to remember, but can scarcely take rank as a law or principle of nature.

587. It is of importance to learn what is the quantity of matter which constitutes the equivalent, as it is often considered to be what used to be called the chemical equivalent. If this were true, and if Faraday's theory were also true,that only molecules consisting of one equivalent of each radical are electrolytes, the old equivalent theory of chemistry would be almost impregnable; but neither of these ideas is true. The equivalent or lowest combining proportion of nitrogen is 14, that of hydrogen being 1; but when pure ammonia is electrolysed, only $4\frac{2}{3}$ of nitrogen is given off for one of hydrogen. When cupric chloride $CuCl_2$ and cupreous chloride Cu_2Cl_2 are electrolysed in series, the first gives one equivalent and the second two equivalents of copper for the same current which, in the battery or other cell, gives one of hydrogen.

588. The new atomic notation of chemistry is based, not only on the facts of chemical combination, but also on the relation of different substances to the forms of crystallization, and to the properties of isomeric and isomorphous bodies; and this view of the constitution of matter also completely covers the facts of electrolysis. It bestows upon the different atoms different combining powers, as the quantities represented by these atomic weights can combine with, or replace, one or more atoms of hydrogen. This property is called the valency of the atom. But the atoms are not only capable of entering into union singly as *ions*, but two (or more) of the atoms of the same element can first unite (in which case they usually condense a portion of their combining powers) and constitute a fresh *ion* or radical, having its own proper valency. The theoretical explanation of this, known as the doctrine of "atomicity," is given in § 6, p. 3; but this doctrine is by no means essential to the comprehension of the facts, nor do the laws derived from these facts depend upon the doctrine of the possession of atomicities by the atoms. These chemical relations have been examined in previous pages from various points of view as occasion required, but they are the basis of electrolytic actions, and their comprehension is essential in the study of the subject of this chapter; they are therefore reviewed here, even at the risk of some repetition. It

is, however, unnecessary to enter into the subject of "atomicity," or to consider whether that doctrine is true or wholly imaginary, or a partial conception which may hereafter develop into a more perfect theory by aid of the revelations of the spectroscope. What we have to do with is *the fact* that the several weights called under this new system the *atomic* weights, do represent in combination chemically, one, two, three, or more atoms of hydrogen. Again, it is a fact that molecules do exist which, in the gaseous state, contain the elements in these ratios by volume; thus HCl hydrochloric acid, H_2O water, H_3N ammonia, each contain these relative volumes of H for one volume of the other gas: when combined they, every one of them, occupy two volumes, the same volume that is, as the molecule of hydrogen HH, and these molecular volumes hold, all alike, the same relation to energy, for they expand equally for equal heats and pressures. All these manifold points of agreement justify the conclusion that these weights are the atoms, and that the molecules are constituted by the union of these different numbers of atoms. *Valency* is, in fact, the *gaseous volume combining ratio* of hydrogen to other elements, or of other elements to the unit volume of hydrogen, but extended by indirect calculations to those elements whose actual gaseous volume cannot be directly measured. The *atomic* weight is the weight of a unit volume of the elements in the gaseous condition, compared to that of hydrogen as unity.

589. As modern science accepts the doctrine that heat is a "mode of motion," and as motion implies space to move in, it is obvious that there must be a relation between heat and the space occupied by the moving particles; heat being only one form of energy, we readily extend this relation to energy in all its forms, and therefore, although we are not yet far enough advanced in actual knowledge to define all the facts and laws, we can see very clearly that there is in nature an exact relation among the weights of the atoms of matter, the spaces they move in, and the energy they absorb, that is to say, between the atomic weights, molecular volumes, and intrinsic energies of substances. We can see in fact that if, by the agency of energy, atoms are made to occupy a different space from that common to them, they must have new properties; especially as there is an evident relation between this space and the powers of atoms to combine; that is to say, under these altered conditions of energy, the *valency* (which is a function of volume and energy) will be altered; as a consequence we can conceive of the existence of two or several compound substances containing the same elements and in exactly the same proportions, but owing to

differences of intrinsic energy having very different chemical properties, and belonging to entirely different molecular types. This may explain "isomerism" (equal measures of the same elements in different compounds); it also explains "allotropy" (different forms of the same substance), as due to different specific energies forming part of the molecules, attended probably with a different number of atoms entering into the molecules, which have consequently different physical properties. Carbon, sulphur, and phosphorus are well-known substances taking different forms, and ozone O_3 is a modified molecule of oxygen, containing three atoms of O instead of two, condensed to the normal twofold molecular volume.

590. Berzelius's electro-chemical theory (§ 518, p. 317), which long ruled chemistry, assumed that each element possessed, as part of its constitution, a definite quantity of positive or negative electricity, which set up the chemical attractions between them; that they united into acid and basic radicals, the attractions of which for each other were due to the excess of + or − electricity not neutralized in the primary act of combination: he therefore drew up a list of electro-negative and electro-positive substances. It will be seen, therefore, that on this view each kind of molecule possessed *different quantities of electricity*, which are the causes of the varying degrees of affinity. But Faraday distinctly proved that there is a relation based upon the equivalent constitution of matter. Thus, if a cell is set up, based upon zinc displacing silver from its nitrate, a definite quantitative result will be effected by the current; if passed into a copper solution, it will reduce a definite quantity of copper, and the quantity will be in the ratio of the old equivalents of the metals—i. e. for 108 grains of silver precipitated in the battery, 31·75 of copper will be deposited in the cell. But copper will precipitate silver, though with much less force than zinc does, therefore it is said that a much lower affinity is at work; if, then, copper is used for a battery with a silver salt, a current will be set up, and this current also will, for the 108 grains of silver in the battery, deposit 31·75 of copper in the cell. Again, iron will throw down the copper, and zinc the iron; in each case a lower affinity at work in the battery produces exactly equal reduction in the cell, though taking a longer time to effect it. But, again, if we place in a series, cells containing different classes of molecules, and pass a current through all—such as salts of silver, copper, and iron—the same current passes through them, and deposits in each cell its metal in the order of its equivalent, 108 silver, 31·75 copper, 28 iron, for each 32·6 of zinc dissolved in a cell of the battery. Therefore Faraday said that every molecule, no

matter what its nature or what the chemical affinity within it, requires or gives up the *same quantity of electricity*, and this is law IV. (§ 586).

591. How shall we reconcile these two conflicting views, for both of them are based on truths? Careful consideration of the facts will show us that Berzelius based his ideas upon the conditions set up by "intrinsic energy," while Faraday's law is based upon the "valency" of atoms and radicals, and consequently upon the construction of molecules.

When we see that electricity is a something wholly dependent on the molecular constitution of matter, that it can be transmitted or measured *only by motions of the molecules*, and those motions transmitted along a definite chain by the action of one molecule upon another, it is easy to see that there must be a relation dependent upon the *number* of molecules moved or broken up, which relation we may, if we please, call a *quantity* or an *equivalent* of electricity, and so take possession of Faraday's labours.

When we learn that energy is an integral part of the molecules of matter; that the component atoms are moving at definite rates, as the spectroscope shows, and that chemical combination is attended with a reduction of that motion, and its release as external heat, or as motion along a line of polarized molecules in electricity, we see why each such action must give up a definite amount of energy, and why, according to its amount, the molecular motion it sets up (the "quantity") shall be slow or rapid, and therefore the stress set up upon the molecular chain shall be great or small in the ratio of the chemical affinities at work. Here, then, we take possession of Berzelius's labours, and connect the two conflicting theories into a more general conception.

592. What is the quantitative relation between electricity and matter? Is it molecular or atomic? Is it dependent on the atomic weight of the modern chemical notation? or is it, as nine people out of ten suppose, dependent upon the old equivalent weights? Upon none of these, and yet upon all of them. Our knowledge is, in fact, not yet sufficiently advanced to enable us to give a definite explanation of the mode of relation between electricity and the molecular constitution of matter. In Table XIII. (p. 319) is given a list of the actual quantitative relations; and a little examination of some of the relations of matter and energy may throw some new light both upon the cause of these relations and upon the chemical constitution of substances.

593. The elements combine with each other in exact definite ratios, and those ratios, as was stated above, have a twofold

aspect: (1) the *weight* of matter involved; (2) the *measures* in the gaseous states. The atomic weights now adopted (Col. III. of Table XIII.) combine both these aspects; they are the weights of those measures which equal in volume one weight of hydrogen. Some substances cannot be so measured, and the figure is arrived at indirectly; some, again, are experimentally exceptions; they may be half or double measures when actually compared as elements, and yet when entering compounds they agree with the accepted figures. This requires explanation: why is a law to be accepted as universal when experiment shows us there are exceptions? Experiment is the foundation of all knowledge, but the deductions from experiment must be broad; they must be based upon the *spirit* not upon the *letter* of the replies which nature gives to our questions. When several different experiments appear at first to differ in their teachings, it is our duty to see if we cannot find some broader road to knowledge of which these are several byways. The relations of energy to matter vary in different physical states, and in the one physical state of gas they vary according as we recede from the point at which the gas becomes a liquid, that which is commonly called the boiling point. Yet through all these variations we see a fundamental law of nature (the law of Boyle and Mariotte, Dulong and Petit); the relation of energy to matter as gas is definite—equal heats, equal pressures, produce equal expansion and contraction. The variations are due to the imperfect gaseous condition, and our inability to compare all bodies at the proper point at which nature fixes that relation; therefore in our experiments we employ part of the energy we use in carrying out some other kind of relation as well as the particular one we wish to examine; that is to say, we do internal molecular work, variable in quantity with each substance. The remedy is, to arrive as far as possible at the knowledge which each experiment gives in one direction, and then to accept the general teachings to be derived from many.

594. It is upon this principle that we may regard the accepted atomic weights as representing the abstract unit gas volumes of the several atoms, and two such unit *atomic* volumes as the unit *molecular* volume, into which nature compresses all the atoms of which she builds up every molecule of known substances. But these atoms do not combine in mere pairs. One volume or atom is *equivalent* to, or can combine with or replace, one, two, three, or more atoms or unit volumes of other elements; yet when so combined—no matter how many volumes enter into union—they condense down to *two* volumes, as shown § 588.

This is so universal that we are bound by the principles of honest reasoning to recognize that the apparent exceptions are due to the different conditions of energy to which we are compelled to expose, in order to compare, them. Taking, then, the unit volume of hydrogen, the lightest substance and the most perfect gas (therefore the simplest known substance in its relation to energy), as our base, we class atoms as equivalent to one, two, three, four, &c., atoms of hydrogen, and call this relation the valency of the atoms. Some substances are capable of possessing several different valencies; thus copper, a bivalent atom, unites with chlorine, a univalent element, as $CuCl_2$; but it also unites with it as Cu_2Cl_2. We know that each atom is not mere matter; energy is also part of its essence; the atom is a vibrating body, and the space it occupies—its unit volume—depends on this motion; we have, then, the right to conclude that copper can part with some of this intrinsic energy, that two ordinary atoms can condense into one, and will then represent matter and energy constituting one atom, occupying one abstract unit gas volume, and having, in its relations to other atoms and to energy, the value of one atom only (and all those properties, chemical and physical, which nature has connected with the unit or atomic gaseous volume), but capable of again absorbing energy, and so reconstituting two atoms.

595. Now energy, in the form of electricity, is related to the atoms and molecules in a manner which links together these other relations. This relation can be formulated as,

$$\frac{\text{Atomic weight}}{\text{Valency}} = \text{electric equivalent.}$$

We can therefore give to Faraday's "quantity," or "equivalent of electricity," a definite value accordant with the chemical constitution of matter; it is that action which will release one univalent atom or radical, elementary or compound; that is to say, it passes along one of the links by which molecules are constituted, as represented in Fig. 43, p. 122; in so doing it acts upon and, in chemical action, releases the unit radical, and exerts a definite magnetic action externally by means of the inductive conditions it sets up in surrounding bodies. To define its electrolytic action still more strictly, it will release one univalent *radical*, which radical may be a single atom, or may be built up of many atoms of any valency brought into that state which corresponds physically and in its relation to energy with the unit gas volume and single valency. This unit of electricity, measured on a grain system, is that used in this work, viz. the equivalent of one grain of hydrogen. Each molecule, therefore, acts in the electric circuit as though it were so many molecules as would represent the "valency" of the two radicals or ions into which it breaks up. How or why this relation exists our present knowledge does not enable us to explain, but that this is the true relation of electricity to matter is certain, for this law covers all the known facts, all the exceptions to the common accepted laws of electrolysis (§ 586); but we can see that it is probably connected with the unit atomic gaseous relation of matter and energy, extended into all other physical conditions.

596. But electrolytes have another relation to electricity besides that of current equivalent. A true electrolyte, setting free its two radicals, requires a definite force exerted upon it, variable, not as before, by classes, but with every single substance according to the strength of what is called the chemical affinity of the two ions.

If we set up a battery and a certain resistance, a given current will pass; extra resistance will diminish the current, but no amount of resistance will quite stop it: an amount $\frac{E}{R} = C$ will always pass. If we set up a battery which will just pass current through a solution of iodide of potassium, and then substitute for this, dilute sulphuric acid, no electrolytic current will pass at all; the decomposition cell is not a mere resistance, but as soon as it is polarized it is a *counter-electromotive force* (§ 265), and is expressed in formulæ as $-e$. This is, in fact, only an illustration of the fundamental law of nature that action and reaction are always equal. If we pull on a rope fixed to a post, the post resists us, and the strain on the rope at the post exactly equals that at the other end; spring balances at the two points would show the same pull in opposite directions. So when chemical affinity is exerted in combination, it sets up an E M F in one direction, a stress on the polar chain; if decomposition occurs, the radicals set free absorb an equivalent energy, and act as an E M F in the opposite polar direction, that is, as a − E M F. Therefore it is that to effect decomposition against any chemical affinity, the E M F exerted must be somewhat greater than the − E M F set up, or no action can occur at all; upon the degree of excess will depend the rate of action. To ascertain, therefore, the amount of electrolysis which can be effected by any battery, and under any conditions of resistance, the formula is $\frac{E - e}{R} = C$.

597. If E and e are expressed in volts, according to the system explained, §§ 253 to 256, R being the total resistance, metallic and liquid of the circuit, C will be a figure which, multiplied by 5·68 to bring it to "chemics," and by the proper figure in Col. VI., Table XIII., p. 319, will give the actual weight in grains set free in ten hours' action.

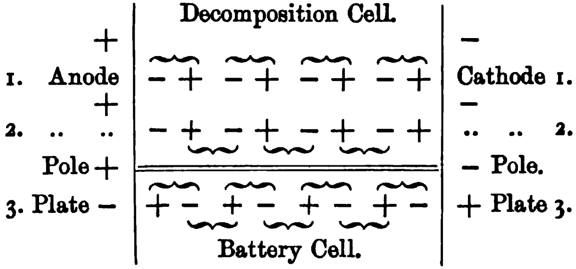
This formula can be extended into giving actual results. If v is the electric equivalent of the substance set free, k a constant representing the hydrogen value of the ampère current, that is for grains 0·000158, for grammes 0·00001022, and equivalent figures for ounces, pounds, &c., E, force in volts, R, resistance in ohms, t, time in seconds, and W the quantity, or work done,

$$W = \frac{k v E t}{R} \qquad (E = E - e)$$

598. There are, however, two ways of looking at the action which goes on in a decomposition cell forming part of an electric circuit. (1) We may regard the solution as a *conductor*, transmitting current exactly in proportion to its resistance. (2) We may regard the solution as a *dielectric*, and the electrodes as condenser plates which we can charge up to a certain potential at which the dielectric breaks down. Each of these views is true, and it is only by combining them that we can obtain a complete conception of the conditions. Treating the cell as a condenser, we may, in fact, see in it the conditions of static charge explained § 40, and the electrodes correspond to the plates in Fig. 25, p. 70; or regarding the anode as a surface taking a + charge, we get fresh light upon the conditions illustrated, Fig. 12, p. 33. In fact, we give the electrodes a charge, the degree of which will depend upon (1) the electromotive force of the battery; (2) the inductive capacity of the interposed liquid; (3) the relation the resistance of the cell bears to the total resistance of the circuit. This view holds good for all liquids (as also for all substances whatever), electrolytes or not.

599. But, in a condenser, the dielectric, though it does not transmit current, or only slowly, is polarized statically in the same direction as though currents were passing, and each charge, each act of polarization that is, absorbs so much energy as the inductive capacity can take up, and necessitates a proportional consumption in the battery; that is, each equivalent chain to be polarized requires an equivalent of action in the battery, and will consequently show a corresponding current

(or molecular revolution) in the connecting wires, &c. We may, therefore, picture the conditions thus—



The first line shows the static conditions as a condenser; the second, the result of electrolysis; and the third, the polar condition of the battery. We see here that, regarding the battery as the source of energy, it polarizes the contents of the cell (1 and 2), and so completes a circuit; but, looking at the cell itself as a reacting source of electromotive force, we see that *in either case* the cell produces a stress in a direction opposite to that of the battery itself, and the diagram shows us why, (1) as a condenser, by giving up the energy stored up as charge, by the strain upon the brackets or molecular affinities, which act like strained springs, or any other mechanical reaction which absorbs and then gives up energy; (2) by the tendency to reunion of the freed ions, which act upon each other through the liquid just as they do in a battery when an acid and alkali are separated by a porous division, § 245, p. 165. Either of these actions will tend to make the anode positive, as will be seen by the order of the symbols + and −; as the battery does the same, the effect is that of two cells in multiple arc or "coupled for quantity"; and all the actions tend to convert the prolongation upwards of the electrodes into + and − poles. The battery and decomposition cell are, therefore, identical in principle with two cells with similar poles opposed, and no current can pass unless the electromotive force of the one cell (the battery) exceeds that of the other cell (the electrolyte).

600. POLARIZATION OF PLATES.—This is the very confusing name given to the condition just described which sets up a − E M F. It was at first supposed that the plates themselves were electrically charged and rendered polar or + and −, and the name has been retained and adds to the variety of meanings attached in science to the word "polarization." This action is

the basis of the secondary batteries, and is fully explained p. 172.

601. COUNTER E M F.—It is generally believed that this is not produced when plates of metal are electrodes in a solution of the same metal, as in coppering. This is not correct. It is evident that the plates cannot be in the *same* solution, because the action itself produces concentration at the anode and impoverishment at the cathode. I have found that this generates a small − E M F and that the copper deposited in a decomposition cell worked by a Daniell cell is never quite equal in quantity to the copper deposited in the battery if worked with a wire having equal resistance to the decomposition cell. I find this − E M F about ·02 of a volt.

602. But M. Lossier has shown that there is another source of − E M F; that the mechanical energy absorbed in the action produces this as it does in magnetizing: he states that "a current traversing any electrolyte develops a − E M F equal to the square root of the current and the resistance": that is, $e = \sqrt{Cr}$. This is in addition to that due to the chemical energy of any decomposition.

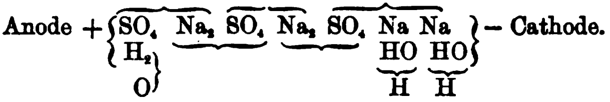
603. The electrodes of a cell are not necessarily metals. When two liquids are separated by a porous diaphragm, the surfaces of the liquids in contact act as electrodes to each other, and the precipitation may occur there just as happens at a plate. A series of liquids may be connected in this manner, and current passed through the whole. The examination of what happens in this case will clear away many very common misconceptions. Thus, it is often said that " ions can be transmitted through materials for which they have a strong chemical affinity without combining with them." Now this is not the case. No ion can be so transmitted. The illustration usually employed represents three connected liquids—sulphate of soda, infusion of litmus, and water. After a time sulphuric acid is found in the water, and it is considered that it must have passed through the litmus solution, yet it has not coloured it. But what has occurred is quite different. Not sulphuric acid, but neutral sulphate of soda, has traversed the solution, by simple endosmose. Until this endosmose has brought some of the salt over no acid would be released, nor would any current pass at all unless some saline substances were in the water. But if in any intermediate solution there is a chemical affinity for one of the ions, capable of producing a precipitate, that ion will never pass across the solution. Suppose there are four solutions, common salt at the cathode, sulphate of soda next, then nitrate of silver, and again sulphate of soda—no particle

of chlorine would ever find its way to the anode, but sulphuric acid would be set free there; any chlorine which either by endosmose or by electrolytic transfer reached the silver cell would there be at once precipitated. What really occurs is a constant interchange of the ions between contiguous molecules along the polar chain, so that when this is composed of different electrolytes in contact, the different constituent ions are soon distributed; but whenever in the course of this distribution two ions come together which have a mutual affinity great enough to cause an ordinary chemical combination, they become insoluble, and drop out of the polar chain. Faraday provod this by decomposing sulphate of magnesia in contact with water in strata one above the other, and with precautions to prevent disturbance by gas: no magnesium found its way to the cathode, but on entering the water it formed a film of magnesia in the middle of the liquids at the line of junction, which served as electrodes to the separated liquids.

604. To understand the chemical actions effected by the current, it is necessary to examine them first in a pure electrolyte, a single substance: and most of these have to be liquefied by fusion. A good example is chloride of silver with silver electrodes: the silver adheres to the cathode and the anode dissolves away, maintaining the chloride of silver constant. This is *Direct* Electrolysis. With a very large number of substances in *solution*, a different kind of action occurs, which is called *Secondary* Electrolysis. I will give the usual explanation of this first, and then show a principle which explains it more perfectly and in better accord with the principles of the electric current.

605. If we electrolyze a solution of sodium chloride NaCl, we obtain Cl at the anode; at the cathode we do not obtain Na, but we have instead of it H, hydrogen, in the proper equivalent proportion: in the solution we have an equivalent also of caustic soda NaHO. But if we electrolyze sodium sulphate Na_2SO_4, we obtain at the anode an equivalent of oxygen O, and also an equivalent of free sulphuric acid H_2SO_4, while at the cathode we have the same as in the case of the chloride; we have, therefore, in this case apparently two equivalents of substances set free for one equivalent of current. The explanation given is this: if we add sodium, Na, to water, we decompose the water, we produce NaHO caustic soda, and H as free hydrogen. Therefore, when we decompose NaCl, we actually set free Na in presence of water, which is then decomposed by *secondary* or purely chemical action. In the case of the sulphate we also set free at the anode (or render nascent) SO_4 a radical which cannot

exist separately, but which likewise acts upon water, H_2O, forms H_2SO_4, and sets free O oxygen, also by a secondary chemical action. We may picture the reaction thus:



$$\text{Anode} + \left\{ \overbrace{\underset{\underset{O}{H_2}}{SO_4}\ \ Na_2}\ \ \overbrace{SO_4\ \ Na_2}\ \ \overbrace{SO_4\ \ \underset{\underbrace{HO}_{H}}{Na}\ \ \underset{\underbrace{HO}_{H}}{Na}} \right\} - \text{Cathode.}$$

The upper row of brackets show the original molecules of Na_2SO_4, of which the end ones break up and react upon the water, which does not enter the polar electric chain. It should be noted that we have here, as in § 582, an apparent production of two equivalents for one equivalent of electricity, as we have at the anode an equivalent of free acid generated, and also O set free, as at the cathode we have free caustic soda and H as gas. If this explanation were true, the E M F required would be that of composition of Na_2SO_4, and that is:

NaO by Table XIII.	14593	foot-pounds
$NaO + SO_3$, by Table XIV.	3139	
4673)	17732	= volts 3·8

There would also be heat produced in the liquid equal to that of the action of sodium on water. Now we know that an E M F of 1·5 volts is sufficient to just set up the action, and that this heat is not generated. To understand what really occurs, and so get rid of the complication of direct and secondary electrolysis, we must distinguish between the actions in the body of the *liquid*, and those which occur *at the electrodes*.

606. *The action in the body of the liquid* consists of molecular motions transmitting the current, and the interchange of ions among themselves as they happen to meet with others capable of combining with them. These actions are entirely of the nature of *resistance* (except as explained §§ 601–2): the current, therefore, will divide itself among any number of mixed electrolytes as among different wires, in the order of their resistance; therefore, in an ordinary coppering solution containing a good deal of free acid, the current will be carried mainly by the acid, because the conductivity of sulphuric acid 1 to 11 of water is 16 times as great as that of sulphate of copper.

607. *At the electrodes there is a selective power.*—This is not based on resistance, but solely upon the ratios of electromotive force absorbed in supplying the requisite energy. If several anions are in contact with the anode, that one will be set free

whose intrinsic energy is lowest; hence in dilute hydrochloric acid, &c., chlorine is selected because its energy with hydrogen is only 4721 foot-pounds, while the other anion present, oxygen, requires 6841 foot-pounds. (See Table XIII. p. 319.) If the anode is soluble, that anion would be selected whose intrinsic energy is highest when combining with the anode, as then it would contribute energy to the polar circuit as + E M F (both these statements are subject to limits which will be considered presently). At the cathode a similar selective action occurs: thus, if a copper solution contains iron, copper only will be reduced, because the − E M F of copper is only 1·26 volts (Table XV. p. 322), while that of iron is 2·07; for this reason hydrogen is not released in presence of metallic salts, except when their specific energy, or − E M F, approaches nearly to that of hydrogen, or under a great excess of E M F. Hence in depositing nickel or iron, hydrogen is always given off, despite of Smee's law to the contrary. The principles I am laying down show us why. The − E M F of iron is 2·07, and that of hydrogen is only 1·9, nearly the same.

608. It is probable that there are cases, however, in which a true *secondary* or *chemical* reaction occurs. Such are those actions in which no direct *ion* is released from a broken-up molecule; but a complete molecule has a part of its constituents removed or substituted, or extra atoms (forming the true ion released) are added to it. Such an action occurs at the cathode when nitric acid is present there; the *nascent* hydrogen reacts upon it in manners varying with the rate of current and the concentration of the acid; if this is weak, hydrogen is given off. In other cases the acid is reduced more or less by the hydrogen removing one or more atoms of oxygen; if the action is strong, a part of the acid HNO_3 is even wholly reduced, the oxygen is substituted by hydrogen, and the radical ammonium is formed, which unites with another atom of acid to form nitrate, thus:

$$\begin{matrix} HNO_3 \\ HNO_3 \end{matrix} + 8H = NH_4\,NO_3 + 3H_2O.$$

609. A corresponding action may occur at the anode by the power of *nascent* oxygen or chlorine. On this account it is dangerous to electrolyze a strong solution of sal ammoniac (ammonium chloride); and I select this example because it is an experiment very likely to be made; it decomposes into ammonium NH_4, which breaks up into $NH_3 + H$ at the cathode, and Cl at the anode, and the chlorine partially reacts upon the salt and forms drops of chloride of nitrogen, a violent and unmanageable explosive: thus $NH_4Cl + 6Cl = 4HCl + NCl_3$.

I give this formula for simplicity sake, but no one knows what chloride of nitrogen is. Some consider that it is really HCl_2N, Cl_3N, but its analysis presents no great inducements and a great many difficulties. But while these actions, which are producible by ordinary chemical reactions, may be regarded as secondary actions of substances set free, it is more likely (and more in accord with the general facts) that, in most cases, the molecules reacting are actually ranged in the polar electric circuit, and that the actions are effected under the influences exerted by the current. We may therefore substitute for the confusing ideas of direct and secondary action the following new definition, which will embrace all the facts.

610. General Law of Electrolysis.—*At the electrodes those substances are set free which absorb, in becoming free, the lowest intrinsic energy.*

That is to say, at the point where the current enters or leaves the electrolyte, any neighbouring molecule, *whether an electrolyte or not*, will be ranged *in the polar circuit*, provided, either that one part of it can unite with the true *ion* turned towards the electrode and the other part can form a free molecule, absorbing from the circuit less energy than the *ion* of the true electrolyte would require in order to become free, or that the true ion can be introduced into this other molecule at a less expense of energy than would be needed to enable it to constitute a free molecule. The substances set free may be thus formed afresh out of materials in contact at the electrodes, not merely separated as ions or radicals from previously existing molecules, although this latter is the fundamental type and general action of electrolysis.

611. This new conception, it will be seen, establishes an analogy between the effects of electricity in electrolysis, and those of heat in destructive distillation. As in this last case the substances arrange themselves in new forms suited to the forces existing in the retorts as degrees of temperature, so in the decomposition cell they arrange themselves in forms suited to the forces existing as degrees of electric tension or electromotive force.

612. Since this work was first published, M. Berthelot has formulated a general law of chemistry, which he calls the principle of maximum work: that is to say, when substances react upon each other, that action occurs which sets free most heat; it is this principle which underlies all the actions treated of in the chapter on electromotive force, and it is evident that M. Berthelot's law of maximum work is the converse of the general law of electrolysis which I have formulated.

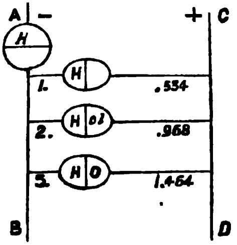
613. MIXED ELECTROLYTES.—In § 459 it is shown that when several paths are open to the current, it divides itself among them all in the inverse ratios of their several resistances. Every conductor is, in fact, a system of such "derived circuits," as the unit conductor is the single chain of univalent molecules. Fig. 72, p. 299, shows that in liquids every part is polarized, and forms a system of derived circuits, of unequal resistance, from every part of one electrode to every part of the other electrode, and as a consequence every portion of the liquid in the cell carries a part of the current proportioned to the lines of resistance in which it enters; but this relates only to the true resistance to conduction, § 606. The conditions are quite different when the different "derived circuits," or paths for current, are different electrolytes; those conditions will also be very different when the electrolytes are in different cells, and when they are mixed in one vessel.

614. As a consequence of the balancing of electromotive forces, when a current enters a mixture of electrolytes and passes along them in the ratio of the resistances, it also decomposes them in the order of their electromotive forces. We have seen, § 596, that it will act on none whose $-$E M F exceeds the potential to which the electrodes can be raised, as shown on an electrometer connected to the two electrodes; yet it may do so apparently. It may at one electrode select one ion alone, and at the other either an ion, originally forming part of the same, or of a different electrolyte; or it may release several and redistribute the other constituents. It will release, first, at each electrode, *such ions as take up least energy*, whether they originally formed part of the same electrolyte or not. If the potential is raised much beyond the point needed for this, ions requiring more energy will be released, in ratios dependent largely upon the quantities present, and in contact with the electrodes.

615. ELECTROLYTES IN DERIVED CIRCUITS.—If, instead of going through a mixture of several electrolytes, the circuit is divided into several branches, or derived circuits, with a decomposition cell in each branch, containing electrolytes of different $-$E M Forces, then a different set of conditions will arise. The result will be governed by the laws of derived circuits, but with modifications due to the presence of these varying opposing electromotive forces. Let Fig. 77 represent three such derived circuits (1) containing sulphuric acid with a copper anode, with a $-$ E M F = ·534; (2) Hydrochloric acid which gives off HCl, the force of union of which being 4523 foot-pounds = ·968; (3) Sulphuric acid with platinum electrodes $-$ E M F = 1·464. If these figures were resistances, the common current would divide

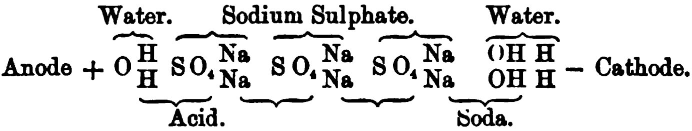
itself between the lines in the opposite ratio, and if each were measured, and the common current were measured also in A, the sum of 1, 2, 3 would be equal to that of A. This latter holds good in any case; if A is a voltameter or a Smee cell, it will give as much hydrogen as 1, 2, and 3 together; but the ratios between these latter will be quite another matter. Until the potential between A B and C D rises to ·534, no current would pass; then it would go wholly by 1; when it rose beyond ·968 a little would go by 2, but only a small proportion; and it would require greater battery power than if 2 were acted upon alone, because by the laws of derived circuits, the E M F would be equal at all the junctions of 1, 2, 3, with A B, and, therefore, the facility of passage opened through 1, would rapidly lower the potential in the common conductors, and make it more difficult to raise it to the degree necessary to pass any current through 2 than it would be were 1 disconnected.

FIG. 77.



616. ELECTROLYTIC REACTIONS.—We may now apply these theoretical principles to actual cells in which well-known reactions are carried on.

(1) The decomposition of sodium sulphate, instead of taking place by "secondary" action as shown in § 605, is effected by molecules of water entering the polar chain itself; the extreme ions of the chain go off as gases, and the formula becomes



$$\text{Anode} + \overbrace{O\begin{smallmatrix}H\\H\end{smallmatrix}}^{\text{Water.}}\; \overbrace{SO_4\begin{smallmatrix}Na\\Na\end{smallmatrix}\; SO_4\begin{smallmatrix}Na\\Na\end{smallmatrix}\; SO_4\begin{smallmatrix}Na\\Na\end{smallmatrix}}^{\text{Sodium Sulphate.}}\; \overbrace{\begin{smallmatrix}OH & H\\OH & H\end{smallmatrix}}^{\text{Water.}} - \text{Cathode.}$$

$$\underbrace{\begin{smallmatrix}H\\H\end{smallmatrix}\,SO_4}_{\text{Acid.}}\qquad \underbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}\,SO_4}\qquad \underbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}\,SO_4}\qquad \underbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}\,\begin{smallmatrix}OH\\OH\end{smallmatrix}}_{\text{Soda.}}$$

The upper brackets show the original molecules, and the lower ones the result of the action; and I have individualized the atoms in order to show why a bibasic salt, such as a sulphate, takes two equivalents of current to decompose it, the equivalent being based on 1H. The student should compare this diagram with that in § 605, and thoroughly realize the difference of principles involved in them.

This reaction requires 1·5 equivolts of energy to effect—that is, so much energy must be given up by the current, in order to set oxygen and hydrogen free, and the cell will act as a $-e$ of that force.

(2) But the anode represents the zinc of a battery cell, and if it can combine with any anion or acid radical present it dissolves like the zinc, and like it gives a + energy to the circuit. If therefore the anode is made of copper, current would pass with less expenditure, and the action would become

$$\text{Anode} + \underbrace{\text{Cu}\ \text{SO}_4}_{+\,1\cdot26}\ \begin{matrix}\text{Na}\\\text{Na}\end{matrix}\ \text{SO}_4\ \begin{matrix}\text{Na}\\\text{Na}\end{matrix}\ \text{SO}_4\ \underbrace{\begin{matrix}\text{Na}\\\text{Na}\end{matrix}\ \begin{matrix}\overbrace{\text{O}\ \text{H}\ \text{H}}\\\text{O}\ \text{H}\ \text{H}\end{matrix}}_{-\,1\cdot92} - \text{Cathode.}$$

Here we see that the energy absorbed is 1·92 − 1·26, or only 0·66 of an equivolt, because at the anode a reaction occurs which gives up energy; or, more simply, there is only absorption at the cathode for setting hydrogen free, in excess of that due to copper solution: if zinc were used in place of copper, still less energy would be absorbed.

(3) We may have at the cathode also, an ion present which requires no more energy to set it free than a corresponding reverse action at the anode will supply, then we have an electrolysis which is only a resistance, not a − electromotive force (§ 606), and which therefore the very feeblest force can effect. If we place copper sulphate at the cathode of the last reaction, it becomes

$$\text{Anode} + \underbrace{\text{Cu}\ \text{SO}_4}_{+\,1\cdot26}\ \begin{matrix}\text{Na}\\\text{Na}\end{matrix}\ \text{SO}_4\ \begin{matrix}\text{Na}\\\text{Na}\end{matrix}\ \text{SO}_4\ \underbrace{\begin{matrix}\text{Na}\\\text{Na}\end{matrix}\ \text{SO}_4}_{-\,1\cdot26}\ \text{Cu} - \text{Cathode.}$$

This is an ordinary coppering reaction, in which, to keep up the analogy, I have used the soda sulphate in the circuit, instead of copper sulphate or sulphuric acid as usual. The copper, in combining with the acid, gives up 1·26 equivolts of energy, as + E M F, and the final act of decomposition absorbs the same as − E M F, leaving only the resistance of the cell to overcome.

(4) In the ordinary voltameter with dilute acid we have a reaction which it will be seen resembles the decomposition of sodium sulphate (1), but the hydrogen comes off at the cathode without producing any other substance there, because the acid itself supplies the hydrogen.

$$\text{Anode} + \overbrace{\text{OH}_2\ \text{SO}_4}\ \overbrace{\text{H}_2\ \text{SO}_4}\ \text{H}_2 - \text{Cathode,}$$
$$\text{E M F} - 1\cdot464$$

giving, besides the resistance of the cell, a − E M F of volt 1·464; so that a single Daniell cell of volt 1·079 cannot pass current at all through this cell; but if we use as in (2) a copper anode, which gives a + E M F ·93, so reducing the − E M F to ·534, current passes freely, hydrogen is given off, and sulphate of copper formed. It will be observed that in formula (2) the corresponding reaction shows a force of 0·66, while here it is ·534, although in both cases the same products are set free. The figures are arrived at by different processes, the data for which are as has been explained very uncertain. Besides this, the presence of the caustic soda in the first case introduces an element which does not exist in the other, and this is the real cause of the greater force required. All these figures are given, however, to illustrate principles as yet understood by very few, not as actually accurate in themselves.

617. WATER NOT AN ELECTROLYTE.—Almost all the books give diagrams, and speak of the decomposition of water; in fact, they commonly attribute the processes of electro-metallurgy to secondary action of the hydrogen set free by the decomposition of water; they speak also of water being a bad conductor, but made better by the presence of acids and salts. The foregoing principles enable us to define *a true electrolyte as a pair of ions which will break up under a potential equivalent to the affinity which holds them together*. It is doubtful whether pure water is not one of the strongest insulators; at all events, it will not only not electrolyze under a potential of 1·5 volt, but it resists a hundred times that E M F: therefore it is not an electrolyte. This point has been often argued. Some have said that alternating currents will decompose water, only the constituents reunite at the electrodes; this plan is obviously merely reversing the charges of a condenser, swinging the water molecules backwards and forwards, not breaking them up, nor passing current through the water at all. Others have tried to diminish the resistance by coiling up two platinum plates separated by silk, giving great area and little thickness of liquid. They passed current, and got gases unquestionably, but it is scarcely necessary to say that it was not pure *water* which was being decomposed. The fact is, really pure water is unknown, even to chemists; it cannot be made, and, if made, could not be kept five minutes. Water is a close approach to the long-sought object of the old alchemists—a universal solvent. The purest platinum, even though made red hot, &c., is sure to have *some* residuary impurities or adherent gas, and thus the conditions of ideal electrolysis are inevitably vitiated.

If the anode be silver, it is found that after a time traces of silver are present in the water, and from this it has been argued that water is an electrolyte, but that its very great resistance prevents current passing. The argument is not valid: when the water is polarized as a dielectric under stress, its oxygen of course will unite with the silver, which passing into solution increases its conductivity.

618. Water and many other substances permit a slight current to pass without undergoing electrolysis; and it has been argued that this is caused by the gases being given off and absorbed by the liquid. We cannot limit nature, nor can we be quite sure that liquids cannot conduct, in some degree, like metals and solids, as even guttapercha does. But there is another point to consider. Water freely dissolves air, and takes up the oxygen in a higher ratio than the nitrogen: it is by this property that fishes are enabled to breathe; therefore when under the influence of the charge, the water, acting as a dielectric, presents its hydrogen to the cathode, it finds there oxygen with which it can combine, while the corresponding oxygen is set free at the anode, with the result of a small current passing: this action is therefore perfectly analogous to the transmission of current across a copper solution between copper electrodes, in fact oxygen is transferred instead of copper.

619. It is stated that acidulated water under a pressure of 300 atmospheres does not decompose, nor allow the current to pass. It should also be understood that there are reasons for believing that the actual electrolyte is not the pure acid, but a hydrate of it: in electrolysis across a porous diaphragm the liquid is carried in excess to one electrode, usually the cathode, to such an extent as even to support a pressure of several inches, as stated § 186. This is explainable if we conceive that the actual electrolyte is not H_2SO_4 but $H_2SO_4+3H_2O$, and that the whole of the hydrogen is given off. Similar results occur with solutions of salts, and electric endosmose is partly due to this excess of transport of water. But if we were to endeavour to represent this exactly in diagrams of electrolysis they would become so complicated as to be unintelligible; also every substance would need to have its own faculty of hydration tested, so that in studying principles it is better to confine the attention to the pure substance.

620. In the various reactions commonly called the decomposition of water, the oxygen and hydrogen gases do not come off pure, and consequently the exact theoretical measures are rarely obtained. Ozone is generated at the anode, and peroxide of hydrogen at the cathode. These are both remarkable substances, as possessing the contradictory properties of being both

oxidizing and reducing agents. Ozone is a molecule of oxygen containing three atoms instead of two, and with the third atom ready to leave at the earliest opportunity; therefore it will take oxygen from an oxidizing agent to form ordinary oxygen, and hydrogen from a reducing agent to form water. The reaction which produces them may be written thus:

$$\text{Anode } \overbrace{\mathrm{O\ H_2}}\,\mathrm{O}\ \left\{\begin{matrix}\mathrm{H\ H}\\ \underbrace{\mathrm{H\ H}}\end{matrix}\ \middle|\ \begin{matrix}\mathrm{H\ O}\\ \underbrace{\mathrm{H\ O}}\end{matrix}\right\}\text{Cathode.}$$

An atom of oxygen released at the anode, and its two atoms of hydrogen acting on two molecules of water, so as to form two molecules of free hydrogen and one of hydrogen peroxide H_2O_2. Three such reactions give three atoms of oxygen to form a molecule of ozone O_3 at the anode.

621. *Small electrodes* facilitate this and other exceptional actions owing to two causes: 1, increased *density of current*, so that the molecules of H_2O in contact with the electrode are more tumultuously solicited by the nascent O, or in other words the common results of relative quantities come into action; 2, the resistance is greater, and the stress on the neighbouring molecules is greater, so that the potential is higher, and conditions exist corresponding to those which cause discharge to occur freely from edges and points, § 83.

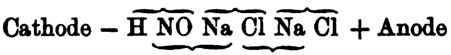
622. Nearly pure water containing air, when electrolyzed by a powerful current, generates nitric acid HNO_3 at the anode, by the nascent oxygen uniting with the dissolved nitrogen and water, and ammonia at the cathode by direct union of nitrogen and the hydrogen, thus:

$$\begin{matrix}\text{Anode}\\ 2\mathrm{HNO_3}\end{matrix}\left\{\begin{matrix}2\mathrm{N} & & & \mathrm{N}2\\ \overbrace{5\mathrm{O\ H_2}} & \mathrm{O} & \underbrace{\mathrm{H_2\ O}} & \mathrm{H}10\end{matrix}\right\}\begin{matrix}\text{Cathode.}\\ 2\mathrm{NH_3} + 4\mathrm{H.}\end{matrix}$$

623. DISSOCIATION.—When a current from a frictional machine enters water by means of fine points, decomposition occurs; it is not, however, *electrolysis*, but *dissociation*; both gases are given off together at each of the electrodes; this is due to the high tensions set up and the violence of the vibrations produced, analogous to the action of a flash of lightning, so that the atoms of O and H constituting water are, as it were, shaken apart. Similar dissociation is produced chemically in water (as steam), and in many substances when the temperature or heat tension rises beyond the degree at which combination occurs. This fact has a striking analogy to the disruptive action exerted in

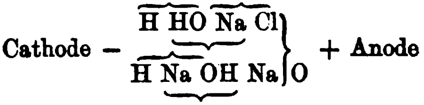
electrolysis when the potential rises beyond the chemical affinities of the radicals, both expressed in the equivolt unit.

624. In the electrolysis of common salt NaCl, for every unit of current one atom of hydrogen will be released at the anode throughout the action; but none of the other reactions will be uniform: at first the action accords with the ordinary laws, and for each atom of hydrogen there will be an equivalent of sodium hydrate at the cathode, and of chlorine at the anode.



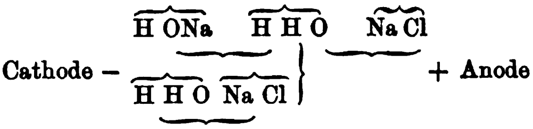
$$\text{Cathode} - \overbrace{\mathrm{H\ NO}}\ \overbrace{\mathrm{Na\ Cl}}\ \overbrace{\mathrm{Na\ Cl}} + \text{Anode}$$

But, as the caustic soda accumulates, it carries a part of the current, and then commences a series of complicated actions at the anode. Chlorine is no longer given off alone, but some oxygen accompanies it by part of the chlorine regenerating sodium chloride thus:



$$\text{Cathode} - \left.\begin{matrix}\overbrace{\mathrm{H\ HO}}\ \overbrace{\mathrm{Na\ Cl}} \\ \mathrm{H\ Na\ OH\ Na}\end{matrix}\right\}\mathrm{O} + \text{Anode}$$

625. The same reaction also extends itself by taking up a molecule of the salt, and forming sodium hypochlorite, instead of setting the oxygen free.



$$\text{Cathode} - \left.\begin{matrix}\overbrace{\mathrm{H\ ONa}}\quad \overbrace{\mathrm{H\ H\ O}}\quad \overbrace{\mathrm{Na\ Cl}} \\ \overbrace{\mathrm{H\ H\ O}}\ \overbrace{\mathrm{Na\ Cl}}\end{matrix}\right. + \text{Anode}$$

In consequence of this and similar reactions, chlorates and other oxygen salts may be formed at the anode when chlorides are electrolyzed, instead of the full equivalent of chlorine being given off. In the electrolysis of hydrochloric acid similar results occur, and oxygen is set free as well as chlorine, and the ratio of oxygen increases as the acid is weaker, because there are more oxygen atoms in the vicinity of the electrode.

It is probable that the electrolysis of salt will play an important part in the practical arts, more especially in bleaching, as it is easy to control the action and to secure the application of the exact quantity of chlorine required without having to leave the fabric exposed for any length of time to the destructive action of acids.

626. These various examples have been selected because they have a deep significance hitherto overlooked. They have been commonly dismissed as slight exceptions from the established laws of electrolysis, or as incidental results of "secondary" action. They really show that this indirect, chemical, or secondary action is a delusion; dismissing it, we can ascend to that higher and more general law formulated, § 610, with all its theoretical and practical results.

627. In electrolysis there is *no direct transfer of ions* from one electrode to the other, but a constant interchange of radicals in contact, which owing to the selective power exerted at the electrodes tends to the accumulation of two classes of radicals, which in the case of salts in solution would ultimately result in collecting all the acids on one side and all the bases on the other, as described § 630; but this could never be effected as many suppose by a current equivalent only to these products, because a continual reversion of the action and diffusion of the products will go on: in practice, also, in an ordinary depositing cell the result of long-sustained action is the transfer of the metal of the anode to the cathode. But the anions or chlorous radicals tend to accumulate most rapidly, and this has important results in electro-metallurgy, because these chlorous radicals act on the anode and surround it with a heavy saturated solution; while the removal of the metal at the cathode tends to produce a weak and acid solution there, just where a dense metallic solution is most desirable; in fact, if we use a neutral solution of copper sulphate in a cell with a porous partition, and drive a strong current through, in a little while the anode will be covered with crystals of sulphate of copper formed there, but unable to dissolve, while the solution at the cathode will be exhausted so as to give the metal only as a powder.

628. The mode of transmission of ions and the way in which the metal of the anode is transferred to the cathode may be represented in the following diagram, in which copper is supposed to be immersed in sulphuric acid:

$$\begin{array}{lll}
 & 1.\ \overset{+}{\mathrm{Cu}}\ \overbrace{\mathrm{SO_4H_2}}\ \overbrace{\mathrm{SO_4H_2}}\ \overbrace{\mathrm{SO_4H_2}} & \\
\text{Anode} & 2.\ \mathrm{Cu\ SO_4Cu\ SO_4H_2\ SO_4H_2} & \text{Cathode.} \\
+ & 3.\ \mathrm{Cu\ SO_4Cu\ SO_4Cu\ SO_4H_2} & - \\
 & 4.\ \underbrace{\mathrm{Cu\ SO_4}}\underbrace{\mathrm{Cu\ SO_4}}\underbrace{\mathrm{Cu\ SO_4}}\mathrm{Cu} &
\end{array}$$

The upper brackets show the constitution before action, and the lower ones the result of one action upon each molecular chain; after each action, which involves a redistribution of the radicals, the newly-formed molecules make a semi-revolution so as to renew the polar condition; at each action, therefore, a molecule of copper sulphate is formed by copper entering at the + end, and hydrogen leaving at the cathode, until at length copper sulphate reaches the cathode, and copper can be set free there instead of hydrogen. The student should compare this explanation with that referred to in § 533. But while he avoids the error of attributing the action to some mythical and general attractive power exerted by the single electrodes for oppositely electrified ions, and clearly realizes that it is a molecular action between the faces of the electrodes and the liquid in contact, he must not overlook the other condition which also exists. The electrolyte is really occupied by a "field of force," such as exists in static charges, and all its molecules are therefore under the static or di-electric stress which plays its part in the action.

629. EXPERIMENTS in electrolysis are very interesting and instructive, and every one who wishes to understand the subject should make them for himself, taking care as far as possible to watch all the quantitative relations of the current by some of the means described in the chapter on measurement. There have been many complicated and expensive forms of apparatus devised, but the most important experiments can be performed by the very simplest means. Wires of suitable metals serve for electrodes, and small U tubes made by bending up pieces of glass tubing will serve for cells, the two liquids being placed separately in the legs; in some cases it may be well to fill the bend with fine sand; straight lengths of tube, closed at the bottom with a plug of plaster of Paris or asbestos, may be used by dipping them in a vessel of suitable connecting liquid. When gases are to be collected, test-tubes can be used, filled with the liquid, closed with the finger or with a piece of sheet indiarubber, and inverted over the wire electrode. The instrument described, § 512, is also admirably suited to electrolytic experiments.

630. By connecting several such cells or U tubes in series, the student will see that the acids all collect in one arm, and the bases in the other; and by using them singly and noticing the electromotive force or number of battery cells needed to pass any given current, he will make clear to himself the relations of the force and observe the reacting current set up, while the conditions of Fig. 77 can be studied by mounting the tubes side by side or in multiple arc. For instance, let four U tubes contain—1. Solution of potassium iodide with a little starch; 2. Common salt, coloured blue with sulphate of indigo;

3. Ammonium sulphate with infusion of cabbage; 4. Copper sulphate. Connected with platinum wires and placed in series with a strong battery, the anode arms will show acid reactions; 1 will be coloured blue by freed iodine; 2 will be bleached by chlorine; 3 will redden by sulphuric acid; 4 will show acid on litmus paper. The cathode arms will show the presence of the bases: 1 will turn turmeric paper brown by potash; 2 will do the same by soda; 3 will become green by ammonia, or blue if litmus is used in place of cabbage; 4 will deposit copper. Used singly or in multiple arc with gradually increased battery power, they will show the differences in the power required for each of these reactions.

631. There are some salts from which oxides are thrown down in a solid form. Such are the nitrates and acetates of lead, manganese, and bismuth, from which the peroxides as PbO_2 MnO_2 are deposited upon the anode. With the lead salts very beautiful effects are produced in this way, as the peroxide in different thicknesses has different colours through which also the metal it is deposited upon may partially appear. By acting on a polished plate with a pointed electrode facing it, rainbow-tinted rings are formed on the same principle as Newton's rings, due to the interference of the waves of light reflected through the film, which diminishes in thickness as its distance from the point increases.

This process is capable of practical application by way of ornamenting metallic surfaces; some attempts in this way have been made, and it offers a very promising field for experiment.

632. The Work of Electrolysis—The formula given § 597 is adapted to scientific and experimental purposes, but for many practical purposes the ampère is too small a measure, and expressions corresponding to the actual operations would be found more convenient. The anticipated requirements of electric lighting, when the current is to be distributed and paid for, have led to the use of the "ampère hour," § 299: but notwithstanding its applicability to this special purpose, the ampère hour ought not to be adopted: it has the serious disadvantage of converting the ampère, which is a unit of *current*, into one of *quantity*, and it is a broken number, as it represents 3600 coulombs, or units of quantity. It would be far better to employ decimal multiples of the coulomb, as is done with other units; unfortunately the usual prefixes do not blend pleasantly with the coulomb, but the proper large units would be the "kilo-coulomb" = 1000, and the "meg-coulomb" = 1,000,000. The following table gives the values in different units of weight

of these several quantities, related to the atomic datum, hydrogen.

Weights.	1 Coulomb.	1000. Kilo-coulomb.	3600. Ampère-hour.	1,000.000. Meg-coulomb.
Gramme ..	·00001022	·010222	·036799	10·22222
Grain ..	·00015775	·157745	·567899	157·74510
Ounce Troy	·00000033	·000329	·001183	·328644
Ounce Avoir.	·00000036	·000361	·001298	·360570
Pound Avoir.	·00000002	·000023	·000081	·022536

If Mascart's ampère value is preferred, § 386, these figures would have to be increased 1·9 per cent., i. e. multiplied by 1·019.

633. Let k represent (as in § 597) the one of these selected as the unit current value, and v the electric equivalent of any substance, then

$$k \times v = \text{W or quantity of the substance.}$$

$$\frac{\text{W}}{k \times v} = \text{Q or} \left\{ \begin{array}{c} \text{electricity required in the} \\ \text{corresponding unit.} \end{array} \right.$$

$$\text{Then } \frac{\text{Q}}{\text{Time}} = \text{Current, and } \frac{\text{Q}}{\text{Current}} = \text{Time required.}$$

In these, time would be hours, if ampère hours were the unit; for other units multiply Q by 1000, &c., when time will be in seconds; or any other ratio can be used.

In practical application another consideration has to be taken into account, viz. the "density of current" suited to the circumstances, which is explained §§ 674 and 698, where also will be found examples of the use of these formulæ.

634. The same principles may be applied in another way, employed by Dr. O. Lodge in his papers on secondary batteries. Thus

$$\frac{\begin{array}{c}\text{Weight of substance acted on} \\ \text{in a single cell in pounds}\end{array}}{\begin{array}{c}\text{Quantity of electricity passed} \\ \text{through it in ampère-hours}\end{array}} = \frac{\begin{array}{c}\text{Ordinary atomic weight} \\ \text{of the substance}\end{array}}{\begin{array}{c}\text{12,000 times the number} \\ \text{of bonds released per atom.}\end{array}}$$

This number 12,000 is a round number in place of 12,020 or 12,098 according to the value used above: it is derived from the fact that 9505 C.G.S. units is the electric quantity corresponding to 1 gramme of hydrogen, i. e. to one "bond" released, according to Mascart's value. The value ·000081 pound in my table is in fact the reciprocal of this 12,000, and the division by the "number of bonds released" is effected in ascertaining the electric equivalent.

635. For practical operations it would be advisable to translate the general scientific terms and values into corresponding special terms; that is to say, instead of reckoning currents in ampères it would be better to measure them directly in terms of the special work; this is, in fact, using an enlarged form of my chemic unit; thus an electrotyper would measure his current in terms of ounces of copper per hour or pounds per day, and an electro-plater would measure them in the ounces of silver corresponding to them. Then galvanometers could be graduated in those units, as I have long been in the habit of doing, and with one controlling each operation, the ordinary workman would understand what was going on, and mere guess-work would be reduced to exact knowledge.

CHAPTER X.

ELECTRO-METALLURGY.

636. Although electro-metallurgy is a purely practical art, and its successful practice may be accomplished with a very small modicum of science, this is true only of the factory; to learn it from books and solitary practice, and in any case to learn it intelligently and to pass beyond the range of mere "rule of thumb," it is necessary to clearly understand the principles in operation, and the terms necessarily employed in explaining those principles, and reference will be made, where required, to the earlier pages in which these may be found. For this reason also, if any one hopes to learn at once how to rival Elkington in the art of electro-plating, or even, having got a Smee cell and half a pint of gilding solution, to at once proceed to gild his watch case or chain, he may as well resign himself to disappointment; he must go through an apprenticeship, by first learning thoroughly how to deposit copper in any required condition; this is a cheap and manageable process, and all the secrets of electro-metallurgy can be learnt there, and, once mastered, success in the other departments is assured, and only slight instructions are necessary for each special case.

637. The first thing essential to be considered is the source of the force, i.e. the best form of battery to employ. We require a battery easy of management, giving a large current at moderate cost and of tolerable constancy. Much will depend upon the amount of use to be made of the apparatus, for the conditions are very different when the instrument is to be kept steadily at work, and when it is to be used only by fits and starts. For most purposes the Smee is to be selected before any other ordinary form; but a careful study of the chapter treating of the different batteries will enable the reader to select the form most suitable to his purpose.

On the large scale the battery is being entirely superseded by the dynamo machine, on account of its greater economy: but I do not propose to go into the use of the machine in this work, which is addressed to general readers, rather than to the details of specific applications; the use of the dynamo is governed by the same principles as that of the battery, its management consists simply in controlling the E M F and the current so as to produce the intended results.

638. The basis of all knowledge is experiment, and the very essence of experiment is exactness; and this latter can be obtained only by regular measurements, a matter rarely attended to in electro-metallurgy. It is impossible to urge too strongly, alike upon the learner and the practical operator, the advantage of keeping in the circuit a suitable galvanometer which will always show whether operations are going on properly, call attention to any irregularity, and measure at every instant the actual work doing, while showing the effect of any variation in the conditions. In this way the work itself soon teaches its laws. For most purposes in metallurgy a vertical detector, § 336, will be found suitable, as not needing exact placing, and not being disturbed by neighbouring magnetic bodies, when, as is usual, two similar needles are mounted on the axis with poles reversed. For experimental purposes, however, the instruments, §§ 332–5, are expressly adapted, and many of the experiments and figures to follow relate to their indications.

639. The various principles and processes classed under the name of electro-metallurgy may be classified and studied under several distinct heads, and sound knowledge can be obtained most readily by carefully distinguishing these heads. The mere process of removing the several metals from their solutions is a part of the general theory of electrolysis, of which it is a practical application; that theory therefore should be carefully studied in Chapter IX., so that in each given case we may secure the metal in such conditions of cohesion, colour, &c., as we desire.

640. There are two completely distinct objects sought in different cases.

(1) We require to form a fresh object in metal which is to have a separate existence of its own, and must, therefore, possess a certain substance and strength; this class of work is usually called *electrotype*, such as forming of copper plates, solid vessels, duplicates of coins, medals, &c., and divides itself into the two cases of deposits on metals, and on non-metallic models the formation of which has to be undertaken.

(2) We require the newly formed metal to incorporate itself with that on which it is placed, and which it is our object to protect from atmospheric and other influences or to beautify; this class of work is called *electro-plating*.

This classification would appear to be the really important one, but this is not the case; for the result is simply a detail of the first head in the next classification to be considered.

(1) The preparing of the object to be deposited upon, including moulding, cleaning, &c.

(2) The actual deposition; selection, and making of the required solutions, and regulating the electrical energy for the due performance of the required work.

(3) The finishing off the completed work. The first and last of these are in the main mechanical operations, and may be considered together.

641. THE PREPARATION OF THE OBJECTS.—Here the first question is: Do we require an adherent deposit, a superficial plating; or do we wish a removable coating, an electrotype? The first can only be obtained upon a metallic surface, and that surface must be of a metal not acted upon to any great extent by the solution to be used; thus it is in vain that we may try to get a coating of copper on an object of zinc or iron in a solution of sulphate of copper. This comes under the second head, however.

642. To obtain an *adherent deposit* there is one essential—cleanliness. And in this sense that word means the perfection of that virtue, not such cleanness merely as will satisfy a scullery-maid, or even her mistress, as to the plates and dishes, but chemical cleanness, the absolute absence of any foreign matter whatever, as such matter, however clean to ordinary ideas, is *dirt*, as Lord Palmerston defined it, matter in the wrong place. Thus, a piece of silver or gold taken off a shelf, however bright and clean it may look, would not take an adherent coat if put into a coppering or silvering cell and deposited upon; on burnishing it probably, on heating it certainly, the coating would blister and strip. The reason is that every substance whatever has a film of air closely attached to it, and the deposited metal forms on this film and not in molecular contact with the metallic surface; thus, in the case considered, the air, however pure it may be, is dirt—i. e. it is in the wrong place, between two surfaces we want to be themselves in absolute molecular contact.

If a surface has been cleaned to perfection, and it be touched with a dry finger, on that spot the deposit will be non-adherent, and in many cases, if cleaned by liquid processes, even a momentary exposure to air will cause the formation of a film of oxide, &c., which, infinitesimal and even undiscoverable as it may be, will still prevent adherence, so that it is of extreme importance to understand what is meant by chemically clean, and how to secure that condition, if it is desired to avoid the most mortifying disappointments.

643. If, on the other hand, we desire a *non-adherent* removable deposit, we require ordinary cleanliness, the removal of loose extraneous dirt, and everything which would interfere with the formation or beauty of the deposit, but we must carefully deface chemical cleanness of surface by means described, § 650.

644. Articles may be cleaned either by dry or wet processes; the first, of course, consists mainly of brushing with the aid of polishing materials, fine silver sand, emery, tripoli, whiting and rouge, according to the nature of the article. It should be observed here that whatever condition we desire in the finished article we must produce in the object before commencing deposition: bright parts should be burnished, and all roughness of workmanship smoothed off, and all file marks and scratches carefully removed. There is, however, this limit to this observation, that in adherent coatings absolute finished polish is not desirable, and even though it is proper to burnish the required parts so as to give a close finish, yet before actual deposition this burnish should be slightly and superficially removed, as perfect adherence is less easy to obtain on an absolutely smooth surface; an instant's dipping in strong acid is enough to give the burnished surface the capacity of adherence without deteriorating from the beauty of finish.

There is reason to suppose that the deposit is not merely a cohesion of two distinct surfaces, but that the deposited metal penetrates to some depth within the surface and forms a partial alloy or chemical union: the hard burnished surface would tend to resist this, while the open granulated surface left by the acid would facilitate the union.

645. The best cleaning and polishing apparatus is in the form of circular brushes mounted upon a lathe; in factories this is always employed in the form of the scratch-brush lathe, a rough affair driven by steam or by a common treadle, with fittings to supply a constant drip of various liquids found to facilitate the action, such as soap and water, stale ale, &c. Amateurs who have no lathe employ the common hand brushes of bristles of various degrees of stiffness; for the harder work of cleaning, the wire "card" is very useful, and for the more delicate work scratch-brushes are employed, in the form of bundles of very fine wire bound round with stronger wire (which is unrolled as the wires wear down). These are made usually of hard brass, but iron is also needed, and in some very delicate work, brushes of spun glass are useful. The same sort of brushes are employed in finishing off the articles after deposition. These

matters being purely mechanical and self-obvious to any one after a little practice, it is not necessary to go further into detail about them.

646. Many metallic substances it is advantageous to heat and plunge into acids; but this must not be done with objects which are soldered, or whose temper or hardness it is necessary to preserve. As a rule, the first thing to be done (where this heating is inapplicable) is to remove the greasy films which most objects acquire either in use or course of manufacture: this is effected by boiling and rubbing in a solution of caustic soda, made by boiling about 2 lbs. of common soda crystals with milk of lime, produced by slaking ½ lb. of quicklime with hot water and well stirring; this will produce a gallon of suitable solution, from which it is not necessary to remove the carbonate of lime formed, as it will assist in the cleaning. The boiling must be effected in an iron pot, not tinned, as tin would be dissolved and deposited upon objects afterwards. After this alkaline bath the objects should be well washed in several waters or under a running stream. They are next cleaned in acids, and again very carefully washed before passing into the depositing vessel; but this stage requires a classified consideration based on the several metals of which they are composed.

(1) *Silver* may be washed in dilute nitric acid, then dipped in strong nitric acid for an instant and washed. It will require no further treatment. There must be no hydrochloric acid or chlorine salts present.

(2) *Copper, brass, and German silver* are immersed in a pickle composed of water, 100 parts; oil of vitriol, 100 parts; nitric acid, specific gravity 1·3, 50 parts; hydrochloric acid, 2 parts.

The nitric acid is of the strength sold as double aquafortis. An acid prepared for the purpose is sold as "dipping acid." Two vessels should be employed for this acid; one fresh, for a final dip of an instant or two, and one partly spent, in which the principal cleaning is effected. If there are green spots of verdigris on the object, these should first be removed by rubbing with hydrochloric acid.

For coppering, this cleaning would be enough; but for silvering and gilding, it is better to coat the surface with a thin film of mercury. This is effected by means of a solution of 1 oz. of mercury in nitric acid with 3 parts of water, diluted to one gallon; there will form a grey or blackish deposit over the surface, which, on brushing softly, gives place to a brilliant coating of mercury; the object should be transferred to the depositing cell the instant this is obtained, otherwise it soon tarnishes, and will require fresh preparation. There should be a little free nitric acid in this mercury solution, and whenever there forms a black deposit somewhat adhering, it is evidence that the mercury is becoming exhausted. Solder, lead edges, &c., give much trouble, as it is very hard to prevent a black line forming at the junction, which prevents silver taking; these spots require treatment with a stronger solution of mercury, or a plan I have somewhat modified from Watt's may be often used: to a soft brush (camel's-hair pencil), tie one or two iron wires of No. 25, or thereabouts, so bent that the points closely follow that of the brush, which is to be dipped in a weak solution of sulphate of copper free from acid, and drawn over the solder, the iron touching it; a reaction is set up, which causes the copper to be deposited in a thin adherent film, on which the electric deposit will fix itself. Nitrate of copper, prepared by dissolving the metal in weak nitric acid, is even better than the sulphate for this purpose.

(3) *Britannia metal, pewter, tin, and lead* should not be dipped in the acid pickle, but rinsed in a fresh caustic soda or potash solution, and transferred at once (without passing into water) into the solution for silvering. The reason is that the oxides of tin and lead are soluble in caustic alkalies, while the products of the action of acids are not soluble.

(4) *Iron and steel* are soaked in a solution of 1 lb. of oil of vitriol in a gallon of water, with a little hydrochloric and nitric acids added. Cast iron requires somewhat stronger solutions and very careful rubbing with sand, &c. Steel, on the other hand, requires weaker solutions. They may often be effectually and speedily cleaned by treating them as anodes in this solution, using a plate of copper as a cathode.

(5) *Zinc* may be treated similarly, but it is desirable to finish with a dip into stronger acids before the final washing. Most of the French "bronzes" are made of zinc, and some do well for silvering on. In these last cases no copper or other metals should be dipped in the baths, and soldered joints must be treated as described above.

These latter classes require special preparations and treatment in the depositing baths, but just the same classification is advantageous there as in the cleaning processes, and the details will be given when treating of the depositing processes themselves.

647. Preparing Old Work.—In replating old goods it is essential that the former silver, &c., should be removed, otherwise a black line forms at the junctions, and sound deposit cannot be obtained. In factories, this is usually effected mechanically by the scratch-brush, with the aid of oil and

rottenstone, and the debris are collected and reduced to recover the metals. The metals may also be removed chemically.

(1) *To Remove Gold.*—Immerse in strong nitric acid, and add crystals of common salt; after a time when the acid is exhausted, evaporate to dryness, and fuse with soda or potash to obtain the gold.

(2) *To Remove Silver.*—Immerse in undiluted oil of vitriol crystals of nitrate of potash (saltpetre), and heat. This may be done in a copper vessel. When spent, dilute largely, and throw down the silver with scraps of zinc, or as chloride, by adding hydrochloric acid. The silver may be recovered from this by fusing with carbonate of soda, or by mixing with zinc cuttings and sulphuric acid, or it may be used for a chloride of silver battery.

This process can be used with articles of copper, German silver, or even brass, but not iron, lead, or its alloys; these should be placed as anodes in a silvering solution, which will not attack the lower metals.

(3) *To Remove Copper.*—From silver, boil with dilute hydrochloric acid.

(4) *To Remove Tin and Lead.*—A hot solution of perchloride of iron (jewellers' rouge, or the druggists' carbonate of iron dissolved in hydrochloric acid) will dissolve copper, tin, or lead, without attacking silver or gold.

648. VESSELS.—For all the foregoing processes, no better vessels can be had than the best hard brown earthenware; for small articles, a kind of basket is made of this material with handle for dipping and shaking about. The same material is available for the plating liquids themselves, though glass is preferable for small operations. For washing, it is well to arrange a succession of vessels with spouts, or slightly inclined, at such a level below each other that a stream of water will flow from the highest to the lowest, so that by rapidly passing the object from the lowest upwards, it is perfectly cleaned; for amateurs, the simplest plan is to hold them under a water tap, and remove them in a pan of water straight to the next stage.

649. CONNECTIONS.—All objects must be securely connected electrically with copper wires. Where it is possible these should be soldered, but usually the connection has to be one of mere contact; for large objects, several wires should be provided: for small ones, such as spoons or forks, little stirrups of No. 30 or 32 wire are best, fixed to a stouter wire, and the points of contact with the object should be frequently shifted, otherwise it will be defaced by a mark when finished. For this reason, the wire actually in contact with the object should

always be as small as possible, though it may be fixed to a stouter wire at a short distance. These connections may generally be attached before cleaning: if otherwise, they should be fixed under water, and with the hands scrupulously clean. It is an advantage to pass these wires through a small glass tube reaching above the level of the liquid so as to check deposit upon the wire itself.

The mode of connecting non-metallic objects is described § 662.

650. **Removable Deposits.—Electrotypes.**—The objects on which these are to be formed should be made simply clean by the removal of loose dirt; if metallic, they should then be lightly rubbed over with a tuft of cotton wool moistened with turpentine, with a piece of beeswax the size of a pea dissolved to the quarter pint; this, when dry, will not interfere with the deposit, but will prevent adhesion. The back and all parts not intended to be deposited on should be covered with varnish or wax for acid solutions, or treated as described, § 663.

651. **Moulds.**—Many of the objects desired to be reproduced have to be deposited, not on the objects themselves, but upon copies or moulds made from them, and some judgment is necessary in selecting the best materials for the purpose; we have to consider (1) of what material the original object is made, and (2) the material which will work best with this, and at the same time suit the particular process of deposition to be used; thus we must avoid using a material which might injure the original, and also one which would be acted on by the solutions; this latter being the case with all resins, wax, and stearine in cyanide solutions. We should regard first the objects to be moulded from, the processes being considered in the order of their advantage.

(1) *Metallic objects, coins, and medals*, &c., are moulded from in fusible metal, guttapercha and marine glue, plaster of Paris, or composition; the surface should generally be rubbed with sweet oil to prevent adhesion; or if it is not objectionable, they may be well polished with plumbago.

(2) *Plaster casts* may be moulded from in plaster, in which case they must be rendered perfectly non-absorbent by the means described § 664; they may also be copied in composition, in which case they must not be so prepared, or the object and mould will adhere, but must be so saturated with water that the surface is moist but not wet, at which stage the composition can be poured on.

(3) *Wax or Sulphur* objects may have moulds taken from them in plaster.

652. **Fusible Metal or Clichee.**—This material has the advantage of requiring no preparation to render it conducting, and is connected by simply pressing a heated tinned wire on any suitable spot, and protecting by varnish the parts not to be deposited on. The principal objection to its use is the dearness of bismuth, to which the ready fusibility is due. The mixtures most available are:

	Lead.	Tin.	Antimony.	Bismuth.	Fuse at
(1)	5	3	0	8	212°
(2)	5	4	1	8	..
(3)	1	1	Cadmium.	2	200°
(4)	4	2	1·5	7·5	151°

The metals are to be melted and added in the order in which they are arranged, stirred well together, and granulated by pouring gently into water. The alloy should then be melted afresh, and granulated two or three times to insure complete mixture. The value of these bismuth alloys arises from their assuming (as solder does also) a pasty condition before setting, and from their expanding in the act of cooling, thus taking a very sharp impression. A small paper case, such as a pillbox cover, a little larger than the medal to be copied, is slightly oiled, and sufficient melted alloy is poured in; it is then placed on a table, and stirred with a piece of card till it becomes pasty; its surface is then lightly swept free of any oxide, by passing the edge of a card over it, and the medal, which should be attached to a holder, is brought sharply and firmly down upon the metal, pressed till it sets, and left on till the whole is cool.

Spence's Metal, which is an easily fusible metallic sulphide, is an excellent material for taking casts, and the process is very similar to that with fusible metal.

653. **Guttapercha** is a good moulding material, and takes blacklead very readily; but as it shrinks in cooling, it must not be used to surround any object, as it would not be removable without injury; for the same reason it requires to be kept under strong pressure until cold; it is, therefore, best adapted to flat objects. It should be well softened in boiling water, and worked together in cool water, and again heated to boiling temperature and formed into a ball, which, being applied to the middle of the surface, is worked out in all directions at the edges of contact, so as to prevent any air being inclosed; and as soon as the whole is evenly covered, it should be put under a weight or press to cool, for which purpose an ordinary copying

press answers perfectly. For large surfaces sheets may be used. They should be warmed, one edge brought carefully in contact, and the sheet gradually lowered while an assistant presses it up to the object; in this case the sheet must be new, as guttapercha oxidizes and forms a hard surface, which would break up and deface the mould. A mixture of two parts of guttapercha melted, and one part marine glue added, is in some respects superior to guttapercha alone. The glue, which has many uses, is best bought, as it is troublesome to make; it consists of 1 lb. caoutchouc, soaked for twelve days (till dissolved) in four gallons of coal naphtha; to each pound of this liquid two pounds of shellac are added, and heated in a closed vessel till incorporated. For guttapercha moulds the objects should be lightly oiled to prevent adhesion. Guttapercha is not suitable for use with cyanide solutions either as moulds or for lining of cells, because it is slowly acted upon.

654. Plaster of Paris.—This is sulphate of lime, or gypsum, deprived of its water of crystallization. This is effected by heating to 500° Fahr.; if heated beyond this, it loses its power of setting, but when properly prepared it has so strong an affinity for water that in combining with it a solid substance is formed. The plaster should be fresh, and it is best to warm it before use in an oven, or over a fire, till it bubbles slightly*; it should then be dropped lightly into a vessel of water, the excess of water poured off, and the material worked up to a paste capable of being poured out. The object to be copied is oiled, and if flat is placed in a frame of sufficient depth and covered with a thin paste of plaster, brushed in to secure freedom from bubbles, and then the plaster is poured over till sufficiently thick. It should be allowed to set thoroughly before removal, and then baked gently to remove moisture. It must be thoroughly saturated with a resisting medium—tallow, stearine, or paraffin; and the best mode of doing this is to place the mould with its face upwards in a vessel containing a little of the melted substance, and heat till the face shows that the protecting agent has been drawn to it by capillary action; then warm the mould gently by itself to remove any excess, and allow it to cool before applying the plumbago. Some use boiled oil, but it is not safe, as it requires to be very thoroughly dried before it can be trusted in the

---

* A very curious phenomenon occurs during this heating of plaster and many other powders; they assume a condition like fluidity, and may be stirred like water: some attribute this to electrification and mutual repulsion of the molecules; but I think it is due simply to the expansion of the film of air which coats each particle, as in § 642, and which also enables a needle to float upon water.

solution. Moulds well made can be repeatedly used, and the saturating material can be recovered afterwards by breaking into pieces and boiling in water, when the substance will melt and form a film on the water when cold.

655. Wax Composition.—Many materials have been recommended; the object of the mixtures is to prevent undue shrinking: this is partly effected by addition of powders, such as flake white, carbonate of lead (which, however, is partly acted on by the solutions), plaster of Paris, red ochre or plumbago (powdered graphite), which assists in producing a quick and even coating. The best mixtures are

Wax.	Resin.	Stearine.
3	..	1
1	1	..

The wax is the ordinary yellow beeswax, and the stearine such as is used for composition candles. The materials should be melted together gently two or three times, and should be poured on the model just as part of the material begins to set, not while fluid. The object is to be oiled and placed in a flat vessel, or if round, as a coin, a piece of paper should be tied round it; it should be slightly inclined when the material is poured on, so that this may rise steadily over the surface, and drive off all air-bubbles; when set, the paper band should be removed and the whole allowed to cool for several hours before the mould is detached. See also § 660.

656. Solid Objects.—Moulds of these have to be taken in two separate parts. They should be bedded to half their depth in fine sand or other powder, in a case large enough for the purpose, and three or four pegs or wires fixed in and projecting from the surface of the sand; the moulding material is then poured on, and when cold, the case is reversed, all the sand removed, the surface of the mould trimmed and prepared so as to prevent adhesion, and then material is poured on so as to inclose the object entirely; when cold the two halves are separated; deposits may be made upon each mould, and the edges united with solder. Some objects may require more than two divisions of the mould, but by similar means (which are, in fact, the ordinary process for casting metals) any complicated object may be copied, unless the elastic mould process is preferred.

657. Busts and Undercut Objects.—The latter cannot be moulded from direct. They can have a mould taken in the

elastic material next described; in this may be formed, of wax composition, a duplicate of the object, from which again a mould may be made of plaster and the wax melted out, thus producing a hollow mould which will be necessarily impervious, and *in which* the deposit can be effected. Hollow silver vessels have been made in this way, by depositing a copper coating on the wax duplicate, which being melted out, silver is deposited within the copper, which is then dissolved off by the process given §§ 647 (3), or by making the object the anode in sulphate of copper solution with a current of low density, as soon as any silver is exposed.

658. ELASTIC MOULDS.—Glue is soaked in water till soft, and then melted in a water-bath as usual, and to it is added one fourth of its dry weight of treacle; this forms an elastic composition such as printers' rollers are made of, and if carefully treated may be melted and used many times. To make the mould, a vessel is to be taken large enough to contain the model, which must be itself duly prepared to prevent adhesion, and if hollow, filled with sand and a stout paper pasted over the opening; the vessel is to be oiled inside, the object stood within, and the composition poured gently over it. After standing 24 hours to cool and set, the whole is shaken out of the vessel, and a sharp clean knife run through from top to bottom in the most suitable line, when with care the mould may be opened and the model withdrawn; the mould is then closed and a stout paper cylinder formed around to support it. This mould is, of course, unfit to use with liquids; a fresh model is formed within it of some mixtures of wax, &c., the composition of which is intended to produce a material which will take a good cast, and will also melt at a heat which will not injure the mould, for which reason also it should be poured in just when it shows a commencement of setting, not when just melted. Equal parts of beeswax and resin, with a little tallow and powdered graphite, may be used, but the preparation described § 660 is best for forming deposits direct upon the model.

659. Elastic moulds may be prepared so as to resist the action of liquids, by adding to the mixture, immediately before use, tannic acid equal to 2 per cent. of the dry glue; or about 1 per cent. of bichromate of potash may be added, or the mould itself may be placed for a minute or two in a strong solution of bichromate of potash: this salt has the property of making gelatine insoluble when exposed to a strong light, which property is the basis of the photographic process of lithography and other modes of reproducing drawings, &c.

660. Parkes's material consists of 5 lbs. beeswax, and 5 lbs. deer's fat melted gently together, with 6 oz. or 8 oz. of the following solution added:—

Phosphorus Solution.—1 part by weight of phosphorus dissolved in 15 of bisulphide of carbon: this has the property of reducing nitrate of silver and chloride of gold, weak solutions of which are to be provided and employed as described, § 661.

661. Insects, Flowers, Lace, and many other delicate objects can be given a beautiful metallic coating.

(1) Immerse in a solution composed of the phosphorus solution (§ 660), to which is added (in proportion to 1 lb. of phosphorus) 1 lb. wax, 1 pint spirits of turpentine, and 2 oz. of caoutchouc dissolved with one pound of asphaltum in bisulphide of carbon.

(2) Immerse in solution of nitrate of silver containing about 1 dwt. of silver to the pint. The object blackens, when it is to be removed and washed; it will then take a deposit, but will be improved by the next solution.

(3) Immerse in solution of chloride of gold containing 4 grains of gold to the pint.

The object should be first carefully attached to the connecting wire before the immersions, and after them washed by gentle dipping into several waters, not with any great agitation, as the metallic coating is a mere non-adherent dust. By this process there may be made the most beautiful objects to be conceived, by a careful selection of the feathered grasses, and some of the finer-leaved flowers; coating with silver, copper, and gold, and producing different colours on these metals, which should of course be in very thin films; they need, however, to be put under a glass shade cemented to its stand so as to be air-tight. Elegant ornaments may be made also from some of the finer Parian and other earthenware covered in this manner, and variegated with bright and dull parts and colours. But the best mode of depositing metals upon *glass or earthenware* is to have gold put upon them by the usual process of burning in, and then depositing upon this; in this way mountings can be attached to the edges of vessels, or metallic figures built up as ornaments, first in copper and then silvered or gilt and coloured at pleasure. *Leaves*, &c., may also be copied by taking a flat sheet of warmed guttapercha, dusting over with gold bronze, or fine plumbago, laying on the leaves, sea-weed, &c., then covering with a polished metal plate, and screwing gently up in a press.

662. Conducting Surface.—The best known process of rendering the surface of non-metallic objects conducting, is to coat

them with a film of plumbago or blacklead. The ordinary article sold for household use cannot be relied on; it is best obtained of a dealer in scientific apparatus, because, though they charge a very long price as compared with the common article, a little also goes a very long way, and much trouble is saved. The gas carbon used for plates, &c., if very carefully ground in water, answers perfectly. The connecting wire should be carefully adjusted to the mould, by imbedding in the plaster, or in other materials, by warming and pressing in, and great care must be taken to make the plumbago film commence in contact with this wire. In large moulds it is desirable to arrange the conductor before moulding, and to solder to it (within the space to be occupied by the mould) a number of fine copper wires, the ends of which are to be placed in contact with various parts of the surface of the object, selecting points not likely to be defaced, and especially the deepest points of any cavities; the points of these wires will form so many starting points and junctions with the plumbago; with medals, &c., it is best to take a wire all round the circumference. Wires may be applied during the first period of depositing, so as to touch the finished mould on its face and form temporary connections which are to be taken away as soon as a complete film has formed over the whole surface. Such wires should be rendered non-conducting, except at the points, by painting over with varnish, so that they shall not take deposit themselves; they should be removed or cut away as soon as a clear film of metal has formed over the whole surface. The plumbago is best applied with a camel's-hair brush, working it lightly in, and occasionally breathing lightly on the surface if the powder does not readily adhere; in some cases, where there is obstinate non-adhesion, the spot may be held for an instant over the mouth of a bottle containing spirits of wine. In some cases plumbago is unsuitable, as when a hollow vessel much undercut or chased is to be copied; in this case the phosphorus solution and process described § 660 is best employed. I have advised the use of powdered graphite in moulding materials, with the object of facilitating this coating and connection, as it renders the materials partially conducting. Some recommend placing the mould in a dilute solution of sulphate of copper, dusted with fine iron filings which precipitate a film of copper mud which is to be gently brushed over the blackleaded surface and into all hollows so as to make a thin layer of copper upon which the deposit forms.

663. *Stopping off.*—Wherever plumbago has accidentally touched parts not intended to be deposited on, and also in medals

when only the face is intended to be copied and yet there is a wire all round, every part not to be deposited on should be coated with a non-conducting film; either resin or varnish or melted wax will answer in acid solutions, but paraffin thinned with benzoline may be generally used.

For *cyanide solutions*, especially when used hot, the very best copal varnish with a little rouge mixed with it, is probably the best stopping. But a composition is used consisting of clear resin 10 parts, beeswax 6, red sealing-wax 4, and rouge or crocus 3 parts, all of the very best quality and melted together.

664. LAWS OF ELECTRO-METALLURGY.—The general laws of the electric circuit studied in Chapter VII. govern the deposit of metals. In the older works on the subject two terms, Quantity and Intensity, were much dwelt on, and the ideas thus set forth still retain their ground and cause much confusion. It was upon these ideas that the leading and most original writer upon the subject, Smee, based his laws, and in order to derive from these past labours what good they can now furnish, and then show how much more advantageous are the results of later knowledge, I will now give an abstract of Smee's own experiments and the laws he deduced from them.

665. SMEE'S LAWS.—When a metallic solution is subjected to voltaic action the metal is reduced, but not always in the same state. If we dip a knife into a solution of copper sulphate, bright copper is deposited; but if we immerse a piece of zinc, the copper is thrown down in a black powdery mass. Again, if zinc is immersed in an ammoniacal solution of copper sulphate, the metal deposited is bright, while iron in a dilute and acid solution of the sulphate reduces black metal. Though these are apparently simple chemical actions, the same diversity of deposit is obtained electrically. Thus, if we take a saturated solution of copper sulphate, and pass through it a feeble current, crystalline copper is deposited; if we dilute the solution with two, three, or four times its bulk of water, the metal is deposited in a flexible condition (which Smee calls "reguline"); on dilution to a very great extent, the metal deposits as a fine black powder. By placing in a tall vessel, quietly, so that they do not mix, a strong solution, then a weaker, and lastly water with traces of acid, after a little while a perfect gradation of strength is reached, and if two copper plates, extending through all the strata, are connected to one galvanic cell, the varying conditions will produce all these classes of deposit at the same time on a single electrode—black powder at top, reguline metal at the middle, crystalline copper at the bottom. From this fact the conclusion is to be drawn that the nature of the deposit depends

upon the strength of the solution. Again, taking a solution of copper, with some acid in it to make it a good conductor, and using with it first a very small cell, then two or three ordinary cells arranged in series, and then a very intense battery, we, with this one solution, again obtain, first a crystalline, then a reguline, and finally a black deposit; showing that the amount of electricity passing also controls the state of the deposit. Therefore "we are forced irresistibly to the conclusion that to obtain with certainty any particular metallic deposit, we must regulate the galvanic power actually passing to the strength of the metallic solution. This is the fundamental principle—the very essence, in fact, of "electro-metallurgy." Hence are derived these laws:—

I. *Black deposit* is produced when the current is so strong, as compared with the strength of the solution, that hydrogen is set free at the negative plate.

II. *Crystalline metal* is deposited when the current is so weak, as compared with the solution, that there is no tendency to evolve hydrogen.

III. Metals are reduced in the *reguline state* when the current so balances the strength of the solution that it is insufficient to actually set gas free, but produces a strong tendency thereto.

There are also two forms of *crystalline deposit*—one of a sandy loose character, due to deficiency of the quantity of current in a strong solution; the second to a large quantity of current as compared with the size of the plate; thus, by using a large anode with a small cathode in a strong solution, large crystals of extreme hardness are produced.

666. There can be no doubt that Smee, by setting forth these ideas, did much towards developing electro-metallurgy; yet they are only very partially true. The experimental bases are imperfectly comprehended, and the laws deduced are incapable of exact application.

Any one who has mastered the relation of current to force and resistance will see, when it is pointed out, that the fundamental experiment is fallacious; for though the same battery and electrodes are in action, the rate of current will vary at different heights, and no certain deduction can be made, except this one, of supreme practical importance—that stratification of the liquids should be carefully avoided by frequent stirring up. It is evident that in such a stratified solution as is described each layer has different conditions of resistance and counter E M F, and therefore an uneven distribution of current results.

667. STRENGTH OF SOLUTION.—An instructive experiment may

be arranged, which does really show the relation of deposit to strength of solution, by preparing six cells, containing—

1. Saturated solution of copper sulphate.
2. " " " 1 part, water 2 parts.
3. " " " 1 " 4 "
4. " " " 1 " 8 "
5. " " " 3 parts, water 1 part, containing $\frac{1}{10}$th its vol. of sulphuric acid.
6. 1 part of No. 5. Water 1 part.

These being arranged in series by means of plates of copper 1 × 1 inch, coated on one side with paraffin, have the current passing under perfect control and necessarily equal in all. By using plates of this size the relations of current to area of surface are also studied.

In such an experiment I have found differences in the qualities of the copper, but nothing like what occurs in Smee's experiments. The teachings as to strength of solution and its influence were but small, for I found good deposits in all with great ranges of current. The teaching as to *quality* of solution was, however, very important, for in all cases the deposit in No. 5 was by far the best—bright coloured, silky surface—even in thickness, and tough in texture; No. 6 came next, and No. 1 was the worst.

668. The real laws of electro-metallurgy are the ordinary laws of the current known as Ohm's formulæ; these have been already fully examined, and we need now deal only with their special application. We have to balance the electromotive force and the resistance of the battery against the resistance of the depositing cells in proportion to the rate of deposit we require, according to the formula $\frac{E}{R} = C$, and we must regulate the *density of the current*, §§ 674, 698 (which we have hitherto had nothing to do with) to the size of surface we have to deposit upon, and the quality of metal we wish to produce.

669. *Electromotive Force* should be kept as low as is consistent with proper speed of working, because it is expensive: that is, we should use no more cells than are necessary in series. Each reaction has an electromotive force suited to it; less will either not work or work very slowly; more is waste, because instead of adding cells to force the work, we ought to correct the resistances to the natural conditions of the work. We should only add cells when we wish to produce a more rapid deposit than the natural state of resistances allows, and then the quality

of the deposit is likely to suffer. The question of cost is of less moment where dynamo machines are used, but the quality of the metal and its colour have to be considered: with machines, however, we have generally provided an E M F in excess of what is required, and the process of management consists in lowering it either by adding resistances or by shunting off a portion of the current.

670. The electromotive forces of the batteries useful for electro-metallurgy are, roughly and for average continuous working, in volts:—

1. Copper, zinc, in acid	·3
2. Platinized silver	·5
3. Daniell	1·
4. Nitric acid cells	1·6

These give results in B. A. units of current or ampères; and if multiplied by 5·68, give the current in chemics, and therefore express at once the weights of any metal deposited in a given time by aid of the equivalents given in Table XIII. p. 319, or in § 632.

The electromotive forces required for depositing metals are, in volts, about:—

1. Copper	·5 to 1
2. Silver	1·5 „ 2
3. Gilding	·5 „ 3.

That is to say, 1 Smee or Daniell is enough for coppering, 3 Smees or 1 Grove for silvering, while gilding may be effected with from 1 Smee to 2 Groves, according to the conditions of the work; providing in all cases power is not wasted by needless resistance, bad connections, thin wires, &c.; but higher forces are required to obtain quick deposits. In fact the real test in all cases is the production of that *density of current* which experience proves to be best adapted to the particular solution and the actual work.

671. *Resistances* should be balanced so as to be about equal in battery and cell. This may be roughly put thus: the surfaces exposed of zinc and negative in battery, of object and dissolving-plate or anode in depositing cell, should all have nearly the same area (except in gilding, where resistance is needed). The resistance may be greatly varied in the depositing cell by changes in size of anode and distance apart. Thus it will be seen in §§ 680–3, that in some cases it is very desirable to have some distance between the plate and the object, which increases

resistance. In these cases this may often be met by enlarging the size of the anode, which diminishes resistance.

672. It is desirable, however, to use large plates in the battery, because large cells work best; and then if small objects only are to be deposited on, and the density of the current is too large, owing to the disproportion, external resistance (as a length of wire) may be introduced, enough to reduce the current to the proper proportion; or if the construction of the battery permits, the distance between the plates or that in the cell may be increased sufficiently for the purpose; or a smaller anode may be used, though this is often disadvantageous.

673. The most convenient regulator is something like the commutator of the galvanometer, p. 208. It can be made on a board about 18 inches long; at the one end is a strong metal pillar connected to the + of the battery, and having a strong spring connected to its upper part, which traverses a number of studs arranged in a semicircle around it: from these wires go along the length of the board, beginning at No. 1 stud and going backwards and forwards to screws in the board, and so from stud to stud, so that increased length of wire is inserted as the spring is passed along the studs: the first wire should be a thick one and the successive lengths may be thinner and thinner, so as to increase resistance: No. 1 stud is also connected to the anode of the depositing vessel, so that any current entering this must pass the regulator.

674. DENSITY OF CURRENT.—According to Ohm's formula $\frac{E}{R} = C$ we can calculate, knowing the elements, the current produced in any case. Thus taking 1 Daniell cell as 1 volt force, and assuming the total resistance as 1 ohm in a circuit in which copper is being deposited, we have 1 ampère per second, or a current equal to 5·68 chemics or grain equivalents per ten hours; under those conditions the galvanometers (described, §§ 332–3) would mark 5·68; and this, multiplied by 31·75, the equivalent of copper, shows that copper is being deposited at the rate of 170 grains per ten hours, or 17 per hour. This is the *total* current, and it is evident that the conditions of the deposit, the quality of metal, &c., will depend wholly on the extent of surface over which it is spread; on a large plate it might be a mere film, on a wire it would be a thick coat. This is what is meant by *density of current*. Now there is a relation between density of current and the state of saturation of the depositing solution, and they increase together; the more dense our current, the more rapid our deposit (not from the solution or total deposit, but for a given area), the stronger our solution may be, and

must be to get good metal. But very strong solutions have drawbacks, to be afterwards considered; and we cannot conveniently alter the strength of our solutions continually. We must ascertain, then, what range of density of current suits our solutions, and then be careful to keep the conditions within that range. If the density of current be too great, we get a sandy or even black powder as a deposit; if it is too slight, we get a crystalline brittle deposit. Happily, the range is considerable within which good results may be obtained.

675. As yet this subject has never been philosophically treated; the facts are known and the matter is loosely described in works on the subject; but no one has, within my knowledge, attempted to deal with it definitely. There is in fact no recognized unit of density of current, because few people in practice have definite ideas upon the current itself. In order that my readers may remedy this, I will fix upon a unit in accordance with the system used throughout this work. Our unit of current is the chemic; call our unit of surface one square inch, then the unit of density of current becomes one chemic per square inch.

676. The object of having a galvanometer in circuit will now be seen, as well as the special advantage of the forms, §§ 332-3. Any galvanometer will show if all is going on right, but these show at a glance, not only the total work doing, but in electrometallurgy will tell us the quality of metal depositing, and enable us to regulate the conditions to produce the effect we desire.

677. TENSION.—The ideas attached to this word now replace those formerly described as due to "Intensity." We are concerned with them at present chiefly as part of the conditions for maintaining the requisite current. But they have also another bearing to which little attention has yet been paid. As seen, §§ 598, 607, the plates or electrodes act as condenser-plates, and the molecules in contact with them will necessarily be under different conditions according to the stresses to which they are subject, which depend upon the electromotive force of the circuit, the resistance between the plates, and the proportion this bears to the total resistance of the circuit. The resulting effect of high tension at the electrodes (that is to say, of a great distance or resistance between them overcome by using high electromotive force) is a deposit of hard metal; low tension produces a softer metal, and this difference is due to the molecular conditions existing at the electrodes themselves; for all other conditions, such as *strength* of current or rate of deposit, and *density* of current, or size of the electrodes, may remain the same, while

the varying hardness of deposit is controlled by the difference of tensions. I have used the word tension here in a general sense rather than the special one of § 75. Here I mean that condition of active stress which accompanies a large **EMF** between the two electrodes.

678. Arrangement of Objects.—This includes the consideration of several distinct sets of principles, as to each of which it is very desirable to obtain clear conceptions: 1. The position—horizontal or vertical. 2. The relative proportions of object and anode. 3. The distance to be maintained. As to each of these, I will give experimental illustrations, which I recommend the student to follow out, and even those practically well acquainted with the subject will find their knowledge become much more definite and exact by carefully examining the conditions of such systematic experiments. To obtain their full teachings it is essential to have in the circuit a galvanometer whose readings are definite.

The solution to be used is that already shown to be best for all objects not acted upon by the acid—viz. 3 parts saturated solution of sulphate of copper and 1 part of dilute sulphuric acid, 1 to 10 of water by measure. I have tested the range of density of current such a solution will allow, and will here give the experiments and results, each having been continued for such time as to give the same weight of copper per square inch of surface.

679. Rate of Deposit.—The unit of density is that taken § 675—viz. 1 chemic of current or 1 equivalent in ten hours (that is, nearly 32 grains of copper), upon 1 square inch of surface; and in the experiments a quarter equivalent was deposited, i. e. 8 grains, giving a thickness equal to stout paper. The experiments were all made with a large Daniell's cell, and the current varied by means of resistances.

1. ·1 unit taking 30 hours: excellent coating.
2. ·2 „ „ 15 „ good tough copper.
3. ·5 „ „ 5 „ a beautiful deposit.
4. 1· „ „ 2½ „ very good.
5. 2· „ „ 1¼ „ sandy at edges.
6. 3· „ „ ¾ „ bad all round the edge.

The first four deposits were hardly distinguishable; the metal was tough and tore without cracking. As with all deposited, and therefore crystalline, metals, none would bear doubling flat; but after heating red-hot, they could be hammered double, and opened without cracking. In 5 and 6 the middles were good enough, but the metal round the edges was of a loose, sandy nature.

It would therefore appear that the *rate of deposit* of copper (that is the suitable *density of current*) should not exceed 1½ units, but that it may be as much less as is desirable without injury to the quality of the metal. This is a rate of about 1 ampère per 6 square inches upon a smooth surface, which is 24 ampères per foot or lb. 1·5 per 24 hours.

Each *metal* however, and each *kind of solution* of each metal, has its own proper density of current, and one solution will vary in the case of inconstant solutions, such as the cyanides, while temperature will greatly vary the suitable density of current.

Also the nature of the surface must be taken into account, as one with projecting points or a granular surface will work badly with the same current which deposits admirably on a smooth surface.

680. POSITION.—Place a strip of copper, at least 4 inches long, vertically in a vessel with a corresponding anode, and pass a small current, leaving the apparatus undisturbed for some days. It will be found that the anode is dissolved away mostly at the top, and if thin, it will be perforated with holes, or even cut completely through at the surface of the liquid. The cathode, or receiving plate, on the contrary, will have a thick coating at the bottom and least of all at the top. The edges will be formed of groups of nodules, forming a thick edging, and the lower corners will show this particularly, and bulge out somewhat. Besides this, in all probability, the whole surface will be marked by vertical lines, mostly commencing in a dot, and forming a sort of prolonged note of exclamation (!). Now repeat this experiment in a rather long narrow trough, or in a vessel with a porous division, or even in two glasses connected together by a siphon or some thick cotton wick, and use a saturated solution of copper sulphate with no acid. In a short time the anode will become coated with small crystals of sulphate of copper, which will entirely stop the current, and the previously noted conditions will be exaggerated at the receiving plate or cathode.

681. The explanation is to be found in the actions described § 627; at the anode copper is being dissolved and the solution becomes stronger; the newly formed salt, being heavy, sinks, and leaves acid when present above; or if the solution is saturated it cannot be dissolved, and is therefore crystallized where formed. At the cathode copper is removed from the solution, which, becoming lighter, rises along the face. Now

take a thin glass beaker, containing water and some light powder, and hold one side close to a Bunsen's burner, and notice the conditions of a heating liquid; a constant stream will soon be generated, rising along the warmest side, flowing along the surface, descending along the cool side, and flowing along the bottom. This circulating stream is due to the different specific gravity of warm and cold water. Exactly the same conditions are produced by the same cause in the depositing vessel; we have a stream of lighter acid liquid rising up the cathode, flowing along the surface, and impinging on the anode, which is there chiefly acted on; this increases the weight of the liquid, and forms a corresponding stream down the anode and along the bottom, which, reaching first the lower part of the cathode, there delivers up most of its metal; in consequence of these two states, the line of least electrical resistance becomes a diagonal one, from the top of anode to bottom of cathode, instead of being uniform through the liquid and at right angles to the surface. Most writers describe this action as due to simple stratification of the liquid owing to differences of density. This is erroneous, as the liquid would not stratify; it is the circulating current of liquid which is the cause of the mischief, and the evil becomes greater as the height of the objects is greater. This current is the cause of the lines and spots. The slightest irregularity of surface (and all surfaces are, scientifically speaking, rough) deviates this current, and the obstruction grows every instant as the metal is deposited.

682. Now, take two good-sized plates and arrange them in the solution horizontally, one at the bottom, the other at the top and at a considerable distance; connect this latter to the zinc of the battery for the cathode. In a little while the current will be stopped, if from one cell; if from several, so as to force its way, the cathode will be found covered with a loose friable deposit, or even a black powder, while the anode will be coated with crystals. Clean the plates and replace them, but make the lower one the cathode. Now a good, even deposit will go on: in this position all requirements are satisfied, the acid dissolves the anode, the product descends and gives up its metal to the cathode, while the liquid being uniform all over the surface, the electric current is evenly distributed. This is the best position, therefore, especially for large flat surfaces and deeply-cut medallions, &c., but it is rarely employed because of its inconvenience, which, however, is much exaggerated. The impurities of the liquid and of the anode are precipitated on the deposited plate and deface it; but this may be avoided by filtering the liquid before depositing, and placing above the

objects a frame fitting the vessel loosely, and covered with muslin or net, upon the surface of which is laid a sheet of filtering or blotting-paper. Of course the leading wires must be coated with a protecting cement.

683. The usual position (and for nearly all except flat objects, the necessary position) is one of vertical suspension; in this case the point of suspension should be frequently changed, the liquids be frequently stirred up, and best of all, the objects kept in constant motion, if possible. Means have been devised to cause a circulation of the liquid, but they have mostly failed, for the very good reason that regular circulation of the liquid is, as already shown, the very thing to be most carefully avoided, unless it is directed in a course opposed to that which would be set up naturally. If irregularities are seen to be forming, they should be removed by filing off, &c., as they constantly increase; but care must be taken to attend to instructions as to the removal of objects, § 695, or else the deposit will be apt to form in non-adherent layers.

684. RELATIVE PROPORTIONS OF ANODE AND CATHODE.—They should be nearly equal in extent; or, the anode should be slightly the larger; if other conditions, as to position, distance, &c., be attended to, the relative sizes matter little as regards the actual deposit going on, but if they differ much, the composition of the solution will alter, especially if large currents are passing. Fig. 72, p. 299, will assist in the understanding of these relations, and also teach how best to arrange the objects so as to equalize as much as possible the lines of resistance, and therefore of proportional current, passing from each point of the one surface to points on the other. As a consequence of the modes of transmission and action of the current described, § 627, there is not in all cases an equal solution of anode and deposit on cathode, and thus the liquid may be impoverished or enriched in metal according as the anode is too small or too large. This applies more to cyanide solutions than to acid ones, because the former are much more complicated in their chemical constitution, and are therefore much more liable to be modified under the influence of the current. But it will occur even in copper salts.

685. THE DISTANCE TO BE MAINTAINED.—Place two small plates of copper connected to a single cell in a large vessel of copper solution, at first about one inch apart, and note the deflection of the galvanometer; now gradually increase the distances and observe the steady fall of the deflection. This indicates that the resistance to the passage of the current increases with the distance between the plates. Bend the

receiving plate into a V form, and present the edge towards the anode, and it will be found that the deposit will be thickest there, gradually thinning away. In the same way, if the receiving plate be a circle or square, and the anode be much smaller and placed near and opposite the centre, the deposit will be found thick in the middle, and thinning gradually away upon the flat surface. The farther the anode is away, the less variation will there be in the thickness of the deposit. If now we draw plans of these arrangements and strike lines across, we shall see the reason is to be found in the principles of liquid conduction, § 484; wherever these connecting lines from anode to cathode are shortest, there will the deposit be the greatest; the electric current distributes itself through every possible path open to it in proportions exactly the opposite to those of the resistances each path offers. Therefore to get even deposits upon the cathode, the anode should be equally distant from all parts of it. This is easy in flat plates, and these may therefore be arranged very close together; in circular objects the same result is obtained by surrounding them either with a large cylindrical anode or by suspending strips all round them. Whenever objects are irregular in form, and especially when the surface is deeply chased or undercut, it may be taken as a sound principle that the distance apart should be considerable in order to diminish the difference of the distances of the prominent and deep parts from the anode; in such cases it is desirable also that the action should be slow, in order to allow the exhausted liquor to be replaced in the hollows by diffusion of the liquid. This is of especial importance in coating non-metallic moulds; in fact, it is well in these to secure deposit first in the hollows, by presenting into them the point of a coated wire, as the only anode at first, for it is by no means uncommon, though very vexatious, to find these hollows obstinately refusing to take a coating at all when a large prominent surface around them has secured a coating, this being so much better a conductor than the film of plumbago. As a rule, better and more even deposits are obtained when the distance is considerable than when it is small; the drawback is that either the rate of deposit is diminished, or else, in order to maintain it, great battery power is required. These are elements of time and cost against distance, but quality of deposit is in its favour.

Another advantage of placing the anode and cathode at a considerable distance is, that it necessitates large vessels and a good body of liquid, conditions opposed to the setting up of currents, and tending, by the greater area of diffusion, to the maintaining a more uniform condition in all parts of the vessel.

This remark applies, of course, to amateurs; in factories the vessels are always large, and the anode plates and objects to be deposited upon are distributed about, according to the number and form of the objects to be operated upon.

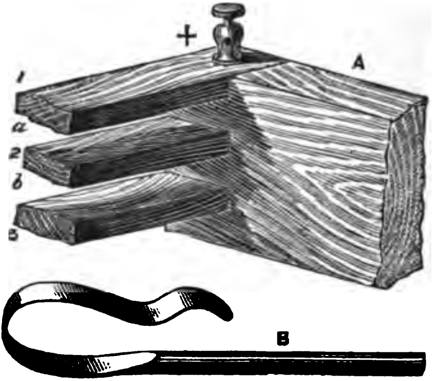
686. In some cases it may be desirable to control and vary the rate of action upon different objects immersed in the same solution, or to ascertain the exact amount of metal deposited upon such objects. This may be easily effected, because a number of electric currents may be passed through the same solution without interfering with each other; it may even be effected from a single anode.

The process is this: instead of using a battery of size suited to the total work to be done, a number of small batteries are to be employed, each adapted to doing the work required upon one article or set of objects. All the positive poles may then be connected to one anode, or a number of plates, distributed about the solution, but acting as a single anode; the negative wires are to be attached separately to the objects upon which each is intended to direct the current, which then, by the ordinary means of resistance and galvanometers, may be controlled and measured. An extension of this principle will be found, § 745, applied to the purpose of controlling the state of the solution and the process, in depositing alloys.

687. DEPOSITING APPARATUS.—It is desirable to provide a means of connecting and arranging the objects without trusting to mere wires, which are also troublesome, and apt to get in contact or to be disturbed. When square vessels are used this is easily effected by having bars of brass across, with a clamp at one end to grip the vessel. Fig. 78 shows the inner angle of a frame which I have found very convenient for the arranging of objects. A is a bar of hard wood with three mortises cut into its end to receive the three flat bars of wood 1, 2, 3; the lower side of 1 and the upper side of 2 are faced with strips of stout sheet brass, or copper silvered, and these are connected to the binding-screw + by turning the ends up outside A. The other end of the frame is exactly similar, except that the lower side of No. 2, and the upper one of 3, are faced or connected to the − binding-screw; thus at the end shown, *a* is a metal-lined opening, having an unlined opening corresponding to it at the other end of the frame, while the opening *b* is unlined and its corresponding one at the other end lined. Metal rods passing through these openings are therefore in connection, the upper ones with the + and the lower ones with the − pole of the battery. B is such a rod, the end flattened out and formed into a spring, which presses upon the plates and allows

the rod to be placed as desired by means of the projecting end. The anode plates are hung upon the upper rods and distributed as required, and the objects are slung by wires from the lower, or – rods, which are connected to the zinc of the battery. This frame can be placed over any vessel if provided with a support, and can be lifted up slightly, and moved about occasionally, to disturb the liquid.

FIG. 78.



688. MOTION OF THE OBJECTS.—The quantity and quality of work done are both improved by keeping the articles in motion. It is evident that the solution in the immediate neighbourhood of the objects is being impoverished by the action, as explained §§ 627–8, because the actual metal is dissolved at the anode and removed at the cathode, while the actual molecular transmission of current may be made in the solution by atoms of hydrogen instead of metal: this of necessity alters the character of the solution; and motion distributes the two different portions. But the current is diminished by the – EMF due to the different character of the solution at the two electrodes.

689. If a cell has a galvanometer in circuit, it will be seen that the deflection increases the moment the electrodes are put in motion: the cell will in fact do from 10 to 20 per cent. more work if constant motion is maintained than if the articles are at rest.

690. The simplest mode of obtaining motion is to mount the anode plates and the objects, or the latter alone, upon a frame such as Fig. 78 fitted with four little wheels running upon a rail on the edge of the vessel, which is with advantage set on

the slope so as to give rising as well as side motions; an excentric wheel and rod attached to a shaft from an engine does the work. Amateurs on a small scale can use an ordinary roasting jack to produce the same effect.

691. DEPOSITING SOLUTIONS.—Before describing the special solutions for use in each case, it will be well to study those general principles applicable to all, the comprehension of which will lead to intelligent and successful working. A perfect solution would be one which contains sufficient metal for rapid working; will give it up freely under the influence of the current; will also freely attack the anode, but only while current passes, so as to keep the quantity in solution uniform; and which has no spontaneous action either upon the metal to be deposited or that on which the deposit is to be effected. All these qualities are rarely combined, but our object is to obtain as many of them as possible. In selecting salts, therefore, we have to consider—

(1) *Chemical Reactions.*—It is *desirable* that the non-metallic radical should have very slight power of attacking the metal, or of forming basic salts with it; thus, sulphate of copper is preferable to nitrate, because sulphuric acid does not act on copper except when aided by extraneous energy, as when the current passes. But it is *essential* that this radical should have little or no tendency to combine with the metal on which deposit is to take place, because this will be sure to prevent adhesion; thus it is impossible to deposit copper direct upon iron from the sulphate of copper, because the sulphuric radical tends to combine with the iron.

(2) *Solubility.*—This has two bearings—quantity and rapidity of solution; a salt may dissolve abundantly and yet slowly; or the liquid may rapidly become saturated, and yet very little be dissolved. Thus, sulphate of copper dissolves freely enough as to quantity, as the solution contains 30 per cent. of the salt, but it dissolves slowly, and the consequence is that as fresh salt forms at the anode it is very apt to crystallize there instead of dissolving, so that it is necessary to have sufficient free water present to prevent this.

Under this head also has to be considered the necessity for the presence of some free solvent besides the salt itself. Thus, in copper depositing, free sulphuric acid helps greatly; and in silver depositing, the presence of free cyanide of potassium is essential to dissolve the cyanide of silver as it forms.

(3) *Electric Resistance, or Conductivity.*—Of two or more solutions otherwise equally satisfactory, one may be a much better conductor than others, and the importance of this is that it requires fewer cells in series to work it, and therefore costs so

much less. It is from this point of view also we must consider chiefly the effect of other substances in the solutions besides those taking part in the chemical action—viz. the metallic salt and the excess of the solvent. As a general rule, such bodies do harm rather than good, for which reasons all formulæ should be regarded with distrust which load the solutions with chlorides, or sulphates, or carbonates of the alkalies, or earths.

692. COPPERING SOLUTIONS.—(1) For all ordinary purposes, that is for depositing upon *non-metallic objects*, upon *copper*, *brass*, *German silver*, and *lead*, the best possible solution is that already mentioned: saturated solution of sulphate of copper diluted with one-fourth of water containing one-tenth by measure of sulphuric acid.

(2) *Iron, zinc, pewter, and Britannia metal* require an alkaline solution. The one commonly used is cyanide of copper dissolved in cyanide of potassium. It may be made by the battery process, which is also available for silver and gold. A large sheet of the metal connected to the + pole of a battery is suspended in a solution of cyanide of potassium of suitable strength (three-quarters of an ounce to the pint), a small plate is attached to the negative pole and suspended in a porous cell in the same solution, and the battery worked until deposit forms on this latter. This plan is convenient for lazy people, but it leaves free potash in the solution, which takes up carbonic acid from the air. The best plan is to throw down a neutral solution of sulphate of copper with cyanide of potassium as long as a precipitate forms. This should be washed several times, and dissolved in cyanide of potassium.

This solution requires to be kept at a temperature of 100° to 150° Fahr., and to be worked with a battery powerful enough to give gas off freely at the cathode or object. About 2 Groves, 4 Daniells, or 6 to 8 Smees, in series, will do this, their size being regulated according to that of the object.

(3) *Watt's Solution.*—Carbonate of potash, 4 oz.; sulphate of copper, 2 oz.; liquid ammonia, 2 oz.; cyanide of potassium, 6 oz.; water, about 1 gall. Dissolve the sulphate of copper in boiling distilled or rain water, and, when cold, add the carbonate of potash and the ammonia. The precipitate formed is redissolved. Now add the cyanide of potassium until all blue colour disappears.

(4) *The best Solution.*—This I have modified from the foregoing, chiefly by omitting the carbonate of potash, which is unnecessary. Per pint of solution the quantities are about: Sulphate of copper, ¼ oz.; liquid ammonia, ¼ oz.; cyanide of potassium, ¾ oz. But the simplest directions are: Dissolve ¼ oz.

of sulphate of copper for every pint of solution required; add ammonia till all precipitate is redissolved, forming a deep blue solution; then add solution of cyanide of potassium till this colour quite disappears; add ammonia and cyanide whenever required to keep the solution in good order. When these are deficient, the anode coats itself with a blue powder; on the other hand, excess of ammonia will make it work badly, as the copper may not deposit, or, more strictly, is redissolved. If the solution is too rich in copper, the metal may come down as a powder: the deposit is in fact a compromise between copper and hydrogen, and it is necessary to attain the happy medium at which good adherent metal is produced. This solution requires the same battery power as the cyanide one; it must be worked also so as to give off gas, but the advantage of it is that it works freely when cold.

As these solutions are expensive to work, they should be used only to form a perfect film of copper. The work is then to be completed in the ordinary acid bath; but great care must be taken in effecting the change to wash off every particle of solution, and to dip the object in acid before putting it in the acid bath, otherwise the second deposit will not adhere to the first.

693. Depositing Copper.—Copper may be deposited by what is called the single-cell process, which is simply arranging the object as the negative metal of a Daniell's cell, as to which see p. 138. A battery and separate vessel is far the best plan. The cell being arranged with the anode connected, and the object being perfectly clean, it should be connected to the zinc of the battery, and immersed without exposure to the air, if adherence is required; if a removable deposit is wanted, then the precautions must be taken mentioned § 650.

694. It is better to use a rather strong battery at first, to secure deposit all over the surface; in fact, this is generally the case with all metals: it is usually an advantage to have the object at first a good distance from the anode, which may be small, so as to have a considerable resistance, and then to use a battery of high E M F in order to obtain the conditions of § 677 and also to make the resistance from all parts of the surface nearly alike so as to resist the tendency to local deposits, and the missing of hollows. After a few minutes the object should be examined without removal, and a soft brush may be passed all over it, especially into hollows, to remove any air-bubbles. For non-metallic objects, it is often better to insert them without a regular anode at first, and to guide the deposit to the deepest hollows and points most distant from the connection by holding

near them a wire, or small strip of copper, as the anode, till a general coating is secured, as described § 662.

695. Objects should not be *disconnected or removed from the solution;* but if a very thick deposit is wanted, it will be requisite to remove the object occasionally, and file away the nodules and irregularities which always form. In all cases of removal, even for a minute, the same precautions must be taken as at first immersion to secure a perfectly clean surface, and the best plan is to dip into weak nitric acid, and instantly place in the bath. Even a minute's exposure to the air suffices to form a slight brownish film of oxide, which, though scarcely visible, effectually destroys the cohesion of the deposit.

696. REMOVING THE DEPOSIT.—When a sufficient thickness has been secured, the object is to be taken out, washed, and allowed to dry, and if it is to be removed (as from a model) all excrescences and overlapping crystals (which are generally rather brittle) must be carefully removed, one edge gently detached, and the coating stripped off when its form permits; in some cases of deposits upon metals this is difficult, but will be facilitated by holding the object over a flame or placing it on hot iron, heating the deposit most. The deposit has at first an extremely rich colour, which would be a most valuable aid to ornamentation if it could be preserved, but unfortunately its endurance is very slight, and a few hours in the air destroys its beauty. For most purposes, therefore, when the surface is to be preserved, not to be used, it has to be prepared by some means of colouring.

697. BRONZING.—*Brown.*—This is produced by a suboxide of copper, obtained of various shades: (1) Moisten with water, to a wineglass of which five or six drops of nitric acid are added, allow it to dry, and then heat till the desired shade is obtained. (2) Rub well in and cover with finely powdered peroxide of iron (jewellers' rouge or red hematite ore); heat till nearly red. (3) Darker shades may be obtained by mixing the peroxide of iron with black-lead, ground to a fine paste with spirits of wine. The copper is to be covered with this paste, and heated till too hot to hold, then brushed well. When the colour is obtained, the objects should be warmed and polished with a cloth, which contains a little beeswax, and all excess of this removed with a clean cloth. A very good effect is also obtained by first bronzing to a deep colour and then lightening the projecting parts by touching with a piece of leather moistened with ammonia.

Black may be produced by polishing with plumbago or by dipping in a weak solution of chloride of platinum: both these require lacquering afterwards. A beautiful dark bronzing is produced by dipping in a weak solution of sulphide of ammonium or of potassium, drying, and polishing with an oiled or waxed cloth.

Green is easily produced by putting a little chloride of lime in a saucer, hanging the object over it, and covering with a shade till the desired effect is obtained.

Verde antique, for busts, &c.—Sal-ammoniac, 8 parts; sea-salt, 8 parts; liquid ammonia, 15 parts; white vinegar, 500 parts. Brush over with this solution several times and allow to dry slowly. There are many other processes, but the foregoing are the most simple and effective.

698. QUANTITY DEPOSITED.—This may be calculated by the figures given §§. 632–3. Thus we may inquire, how many pounds of copper can be deposited in 24 hours upon an area of 3½ square feet. The mode of estimating this applies to every other form and to every other metal by simply replacing the special figures used in this case by those suited to any other case.

Thus we learn in § 673 that the limit of density of current for copper is 24 ampères per foot, so that the current here would be 24 × 3·5 = 84 ampères, and 84 × 24 = 2106 ampère-hours. Then the table § 632 gives us the ampère-hour value, and the electric equivalent of copper being 31·75, we have

$$31{\cdot}75 \times {\cdot}000081 \times 2106 = 5{\cdot}42 \text{ lbs. of copper.}$$

If worked out in detail, the student will see clearly what changes are necessary to adapt the formula of § 633 to any case.

k,	Ampère grain unit,	·000158 ..	$\bar{4}$·1986571
v,	Copper equivalent		1·5017437
	Grains to lb. 1 ÷ 7000		$\bar{4}$·1549020
C,	Ampères per foot ..	24·	1·3802112
T,	Seconds per hour ..	3600·	3·5563025
	Hours	24	1·3802112
	Area in feet	3·5	0·5540680
	Copper deposited	5·32 lbs.	0·7260957

In good actual working the current is not pushed to this degree. In electrotyping the plates for the Ordnance Survey the rate of deposit is about ¼ lb. per 24 hours, which is only half the above amount.

699. CYANIDE OF POTASSIUM.—The commercial article varies so greatly in quality, that it is almost useless to give quantities for use. There are two sorts, the white which is commonly used, and the black which is the best. The white cannot con-

tain more than 75 to 80 per cent. of the pure cyanide, the rest being cyanate of potash necessarily produced in the reaction; but, according to the impurities of the materials used, and the care taken in making, it may contain as little as 50 per cent. Indeed, I have purchased cyanide containing only 50 per cent. from some of the first houses. It is so easily prepared that it is better to do so than to buy it, except with a guaranteed percentage. It is prepared from ferrocyanide of potassium (yellow prussiate of potash) and carbonate of potash, the latter of which is the common source of impurities, of which sulphate of potash is the most important, as it is not only useless, but destroys also its equivalent of the cyanide first produced. The ferrocyanide is to be crushed and dried very thoroughly upon a heated iron plate till the water of crystallization is driven off and a perfectly white powder produced, of which eight parts are to be taken by weight to three parts of carbonate of potash similarly dried These proportions give one equivalent of cyanate of potash to five of cyanide, and form the white product. By adding 1½ part of finely powdered charcoal the whole is converted into cyanide, and the product is black through a remaining excess of carbon. An iron crucible or pot, carefully freed from any rust, is heated to a low red, and the materials (very thoroughly mixed and still warm) are inserted by degrees and brought to perfect fusion, in which they should be kept for twenty minutes, stirring occasionally, but kept covered at other times; the stirring is effected with an iron rod, which is to be examined; the coating it brings away is at first brownish, at last becoming a clear porcelain white, when the operation is complete. This gradation of colour cannot be observed when charcoal is used, but the diminution in the gas given off by the fused liquid, which should be kept at a just visible red, will indicate the completion of the reaction. The pot should then be removed, allowed to stand a minute or two for the iron to settle, and the clear liquid poured off upon an iron slab, broken up and bottled tightly while warm, as it is deliquescent and deteriorates by absorbing carbonic acid from the air. The residuary iron and cyanide should be scraped out while hot and placed in water, and the solution filtered off for immediate use in precipitations, &c. N.B.—It is one of the deadliest of poisons. It will not keep in solution.

The formula and result of the process described is, for pure materials,

$$\begin{array}{cccccccccccccc} K_4 & Fe & Cy_6 & + & CO_3 & K_2 & = & 5\,KCy & + & KCyO & + & Fe & + & CO \\ 156 & 56 & 156 & & 60 & 78 & & 325 & & 81 & & 56 & & 44 \end{array}$$

The last two products, iron and gas, are inevitable loss, and the KCyO, nearly one-fifth of the product, is useless, which the addition of carbon sufficient to convert this O into carbonic acid makes useful, and raises the product to 6 KCy = 390.

700. TEST FOR FREE CYANIDE.—It is very convenient to have the means of ascertaining at any time the exact quantity of free cyanide in any solution, and the percentage of the real substance in any sample. I have, therefore, devised a system based upon the ordinary decimal measures obtainable anywhere, and upon the basis of one ounce of cyanide per gallon of solution; from one to two ounces being the proper working strength. One ounce per gallon is equal to 62·5 grains in 10,000; the equivalent of cyanide of potassium is 65, and it takes two of these to precipitate and redissolve cyanide of silver from the nitrate of silver, the equivalent of which is 170. The test solution, therefore, is prepared from pure nitrate of silver, 81·72 grains dissolved in a 10,000-grain flask of distilled water; 8·172 grammes in a litre make the same solution, which is equivalent, bulk for bulk, to a solution of one ounce of cyanide in a gallon, and may be used with any measure whatever, properly divided. I prefer to take 1000 grains of it and make it up to 10,000 again; to take 100 grains of the solution to be tested, by means of a graduated pipette, and then add this weaker solution to it from an ordinary alkalimeter. As soon as the precipitate ceases to redissolve on shaking, the test is complete. A slight cloudiness in the liquid marks this point.

To test a sample of cyanide dissolve 62½ grains in the 10,000-grain flask and treat this in the same way. Thus, if a sample is so treated, 100 grains placed in a small flask or bottle, 1000 grains of the test put in an alkalimeter and dropped into the flask as long as the precipitate disappears, and upon adding 520 grains in this way a permanent faint cloudiness is produced, the sample contains 52 per cent. of real cyanide. If the original test solution is preferred, 1000 grains of that to be tested must be used, and the result is the same.

701. TEST FOR SILVER AND GOLD IN SOLUTION.—This can be roughly ascertained by the quantity of cyanide necessary to redissolve a precipitate; but as cyanide does not keep in solution the test must be prepared when required. Make a solution, and test its value as pure cyanide as just described. Take a measure of the solution to be tested, and throw down the metals with sulphuric acid, washing the precipitate till all acid is removed; add the cyanide solution from a graduated vessel, stirring, till all is redissolved. Calculate the quantity used as grains of pure cyanide, and every 65 grains indicate 108 of

silver or 197 of gold, but not correctly in old solutions owing to the other metals present. A known measure of the cyanide solution in excess of what is needed to dissolve the precipitate may be used, and the excess measured by the process for free cyanide and deducted from the measure used; it is more easy to hit the exact quantity by this means.

702. SILVER SOLUTION.—There are many different formulæ given in various books, and many have been patented, but as there is only one which is really satisfactory, I shall give only a few words to the others. Some recommend the use of ferrocyanide of potassium instead of the cyanide as a solvent; it is no economy, and the solution renders the silver very liable to strip. Hyposulphite of silver in hyposulphite of soda quickly spoils by the action of light. Chloride of silver in chloride of sodium deposits a chalk-like coating useful for some purposes; it answers well for clock and other dials, and may be applied by simply rubbing on and well washing, just as well as with a battery for this purpose; it has no advantage as a solution for use in the battery process. All the processes which involve the dissolving of oxide, carbonate, or chloride of silver are bad; they waste materials and load the solution with salts of potassium much better absent. Cyanide of silver dissolved in cyanide of potassium is the only solution which can be recommended. It may be and is commonly prepared by making a solution of cyanide of potassium of the desired strength (¾ oz. to the pint), hanging in it sheets of silver connected to the positive pole of a battery, and inserting a porous cell, containing the same solution and a copper or iron plate connected to the negative pole. If current is passed until a deposit forms on this latter plate, the solution will be of proper working strength. The only advantage of this process is the saving of a little trouble, but it leaves in the solution an equivalent of caustic potash, which absorbs carbonic acid and so loads the solution with an unnecessary salt which does at least no good. The best way is to prepare the solution chemically.

703. *Silver Nitrate* is readily prepared by dissolving in nitric acid; the latter varies so in strength that it is useless to give quantities; the solution is aided by moderate warmth. Commercial silver with copper present answers perfectly, and it is not necessary to crystallize if the excess of acid is carefully neutralized with carbonate of soda; it is best, however, to buy crystallized nitrate of silver, which can be bought for little more than the value of the silver it contains, as it is a by-product in several large operations.

704. *Silver Cyanide.*—A weak solution of silver nitrate is

prepared, and a solution of cyanide of potassium very carefully added as long as a white precipitate forms. It is even better to pass hydrocyanic acid into the solution, but as this (prussic acid) is so deadly a gas, the greatest care is necessary, and the operation ought to be effected in the open air. This process, which is the same as is described (§ 718) for recovering spoilt solutions, throws down the cyanide of silver without any risk of wasting silver. When all the silver is precipitated, the solution should be vigorously stirred or shaken, and allowed to settle, the liquid poured off, and the precipitate washed, and solution of cyanide of potassium added, and stirred up till it is dissolved; it is then diluted to the required strength, and the proper quantity of free cyanide added. The precipitate should never be dried, as this alters its properties, and it will no longer make a good solution. After solution it may be crystallized as the double cyanide of silver and potassium, if desired; this makes a good solution at any time.

705. *Strength of Solution.*—About 2 oz. or 3 oz. of silver to the gallon is a good working strength. As the ounce of silver is 480 grains, and that of nitrate 437½, 190 grains of crystallized nitrate of silver to the pint or 3·45 oz. per gallon, will give a solution equal to 2 oz. of silver per gallon. Strong solutions will work more quickly than weaker ones if ample battery power is used, but they require much more care in working to get a good result. The free cyanide should be equal to about half the weight of silver in solution. With less, the solution conducts badly; with more, it is apt to dissolve off silver from both anode and objects.

706. SILVER DEPOSITING.—An experiment devised for lecture purposes some years ago, exhibits in so striking a manner the fundamental principles of electro-deposition that I cannot do better than describe it, and invite readers to repeat it for their own instruction. Take a clear glass vessel of some width, and cut a strip of wood to go across the top; prepare three narrow strips of copper, as long as the vessel is deep, and fit wires to them; fix one in the middle of the bar of wood, and the others (whose wires are to be long enough to reach to a battery, and allow the bar to be moved about) one on each side, as far apart as the vessel allows, all three being in one plane, but not touching; fill the vessel with a good silver solution; connect the outer plates to a strong battery—one Grove or bichromate, or four Smees will do—and then steadily lower the plates in, watching them with a strong light upon them. One remains unaffected, the middle one takes a bluish tint, the third becomes, as by a flash, a dead white.

The middle one acts chemically on the solution, is partly dissolved itself, and precipitates on its surface a film of silver, through which the copper is visible, giving the peculiar colour; no length of time will greatly thicken this deposit; but if, after a time, it is connected to the battery and regularly coated, in all likelihood the deposit will blister or strip under the burnisher. The plate connected to the zinc of the battery receives a true electric deposit, which under good conditions is so rapid as to produce at once the dead white or "mat" silver. The plate connected to the positive pole has been changed in its electro-polar relation to the liquid, the silver sides of the molecules are turned from it, and the action of the cyanogen radicals is exalted; it therefore dissolves more rapidly than under chemical affinity alone, and it can no longer precipitate the silver; or, at least, if any such chemical deposit does still occur (which can neither be proved nor disproved), the silver so thrown down chemically is instantly redissolved electrically.

It is evident, then, that objects to be coated should be connected to the battery *before immersion*.

707. Now take a strip of copper and one of silver, connect them to a delicate galvanometer, and plunge them into the solution; it will be found that a considerable current is generated; this teaches us that we should not *commence* the deposit in a vessel in which objects already coated are at work, because any combination will generate its own current, quite regardless of all other currents passing in the same vessel, and thus a current will pass between the new object and those already coated, notwithstanding that both are alike connected to the same pole of a separate battery. If one bath is employed, a separate battery should be used, both + poles connected to the same anode if we please, but the new object connected by itself to the zinc of one battery, until coated, when it may be transferred to the other connections.

708. The proper plan is to have one large bath, in which nothing shall be inserted but articles already silvered; by this means it is kept from being contaminated with the base metals. Other smaller quantities of solution should be kept for giving the first coat, and made suitable for the different metals, for a good deposit cannot be obtained upon Britannia metal and the other pewters from a solution in which copper has been plated; they also require much more free cyanide of potassium than copper, brass, or German silver do; all these may be coated in the same bath, but one at a time. For the proper preparation of the objects and mercurializing to assist adhesion, see § 646 (2).

709. The first deposit, especially with the baser metals, requires to be effected under greater E M F than ordinary working, but not with too large a current—that is, too quickly. The way to effect this is to employ a powerful battery of small cells, and to use only a small anode, on the principles described § 694. The E M F must not be such as to give off gas.

710. In any case, after the first deposit is perfected, the object ought to be removed, washed, and well scratch-brushed, to see that the deposit is perfectly adherent, as it is more pleasant to strip it and start afresh then (if necessary) than after the whole operation is supposed to be completed. When a thick coat is to be put on, and especially if there are ornamental edges and points, it is well to examine now and then, and if any nodules or roughnesses are forming, to file or work them off, perfectly cleaning the article before replacing. Objects should on no account be touched with the dry hand, but kept under water containing a little soda or potash, or cyanide of potassium, and handled only with perfectly clean hands.

711. DISCONNECTED OBJECTS.—An interesting experiment will illustrate the precautions necessary to observe with objects, and also that peculiar state of the liquid which is called *polarization*, and which is the primary condition of electric transmission. Suspend two plates, connected with a battery, as far apart as the vessel allows, or, say 6 inches or 8 inches; in the centre of two plates of copper, an inch or so square, punch holes, and rivet them firmly on the ends of a stout wire. Now suspend this arrangement in the liquid between the plates, but not touching either, and having no metallic connection with the battery, but isolated in the liquid. After a little time it will be found that the end facing the anode is well coated with deposited metal, while the other end has evidently been dissolved; the intermediate wire will share these two conditions up to the middle, but the principal action will be on the ends. The system has been, in fact, polarized in the same manner as cylinders are, in static electricity, when approached to a conductor, and the action is distributed in exactly the same way as a static charge would have been, in the opposite ratio to the resistance between each particle and the conductor. This shows that objects should never be left in the solution when not being deposited on; if an object accidentally falls from its wire, it should be at once removed and rearranged, for, if left, this effect will be produced upon it.

The effect is not well observed in a silver solution, owing to the chemical action of the copper itself, and it requires a strong current; in a copper solution the action is strikingly visible after a few minutes.

712. **Anodes.**—These should be sheets of pure silver, around the tank; or in small vessels strips of various sizes may be used, so as to be distributed about the objects as required. They should not be attached to copper wire, which is acted upon, though it is greatly protected by a thick coat of solder over it; they should be soldered to stout iron wire, or to strips of lead, which the solution does not act on, and these should have strips of copper, well silvered or gilt at their upper parts, for slinging upon the connections to the battery.

713. If the anodes become coated with a greyish coating, the solution wants more cyanide. When common silver is used, the anodes in this case turn red or purple, owing to cyanides of copper, &c., forming; but pure silver should be used, so as not to keep adding copper to the solution.

714. **Working the Solution.**—A new solution does not work so well as one in constant use. The carbonic acid of the air acts upon the cyanide of potassium, which therefore requires to be occasionally added; the need for this is indicated when the action becomes sluggish, or the anodes and objects become discoloured. If the objects alone are dark and dirty in appearance, instead of a clear chalk white, or rich cream colour, the current is too strong, and the anodes should be reduced in size, or placed farther away from the particular object, or, if the fault is general, the battery power may be reduced. Experience alone can teach all these details. The temperature should be the average one of 60° to 70° Fahr.; when it is colder, the solutions do not work so well, and, if hotter, less battery power will be required.

After a time, a precipitate usually forms, as a greyish-white flocculent powder, which is easily stirred up, and apt to settle on the articles, the solution should therefore be occasionally filtered. The precipitate is mainly impurity, but in some cases it may contain silver, so that it is as well to collect it, and when worth while, burn it in a crucible, with a little nitrate of potash added.

715. **Bright Deposit.**—Silver from the solution described is deposited of a beautiful dead white or "mat," but it may be deposited with a brilliant surface, as if burnished, by adding bisulphide of carbon to the solution. About an ounce of this is shaken up in a bottle with a pint of strong solution of cyanide of silver, and plenty of free cyanide. This is added occasionally as required, little by little, to the bath. It should not be used on the small scale, as it is offensive and unwholesome; excepting

when in regular use, it is also apt to spoil the solution. The bright solution is usually only used to finish articles in as it does not work so satisfactorily as the other.

716. Finishing the Work.—On removal, the object should first be dipped in water containing free cyanide, then rinsed in boiling water, allowed to dry, and placed in sawdust (box or mahogany, not pine). All parts intended to be bright should then be scratch-brushed, either by the lathe or by small hand-brushes; hard hair brushes with fine sand or Bath brick may be used. After this, the surface should be polished with tripoli or rotten-stone, and whiting and rouge, and then burnished with brightly polished steel or agate burnishers, which are made of various shapes to suit different work; the object should be kept wet with soap-suds while burnishing, or some use stale ale. This is an operation requiring much practice to do it well, and it is in fact a special business. Care should be taken to make the strokes of the burnisher always in the same direction, or only slightly deviating from it where markings require burnishing down; the strokes should never be crossed.

717. Spoilt Solutions.—From various causes, and chiefly from the gradual accumulation of the salts of potash, resulting from the action of the air upon the free cyanide, the solutions in time become bad; they do not deposit metal of good colour, or the deposit tends to strip under the burnisher. It then becomes necessary to recover the metal and make fresh solution. Two processes are commonly recommended: (1) To add acid until all the metal is thrown down, and then melt the precipitate after drying; this process is a dangerous one and must be effected in the open air, as poisonous gases, chiefly prussic acid, are given off. The residue must also be fused by degrees, as the cyanide of silver does not fuse quietly; it is better to reduce it with zinc and a little hydrochloric acid—this also in the open air. (2) Evaporate the solution to dryness and fuse till the silver is reduced, and wash off the cyanide of potassium, which generally carries some of the silver with it.

718. The plan I recommend has the advantage of economy of materials, and freedom from danger or nuisance. Place the solution in a large flask, fitted with a safety-funnel and delivery tube joined by an indiarubber pipe to a wide glass tube, the end of which dips half an inch into a solution of silver nitrate in another vessel. Now add sulphuric acid gradually by the safety-funnel, allowing the effervescence to subside, and shaking the flask occasionally; continue adding acid as long as it produces any fresh precipitate. Then by means of a sand-bath, heat the flask and keep the solution boiling as long as a pre-

cipitate continues to form in the other vessel. The precipitate is pure cyanide of silver, and only needs dissolving in cyanide of potassium to form the fresh solution. The precipitate in the flask is also cyanide of silver, but not pure, though sufficiently so for use in most cases; if it is preferred it can be reduced by zinc and hydrochloric acid, or dried and fused. This process saves the cyanide of potassium otherwise required to precipitate the silver.

719. GILDING SOLUTION.—There are many formulæ given for dissolving chloride, oxide, or fulminate of gold in cyanide of potassium. These are all troublesome, expensive, and the last dangerous. The best plan is to dissolve cyanide of gold in cyanide of potassium. The strength should be from half to one ounce of gold per gallon, and it may be prepared by the battery process, exactly as described for silver. It is, however, better to prepare the cyanide chemically. Pure fine gold should be used, but it may be obtained from any alloy by dissolving in aqua regia (1 part nitric, and 3 of hydrochloric acid), pouring off the clear liquid and washings of any residue, evaporating off free acid, and precipitating the gold by protosulphate of iron (green vitriol or copperas), of which about five times the weight of the gold should be used. The gold is found (after standing an hour or two) perfectly pure as a dark brown powder. This, or "fine" sheet gold is to be dissolved in aqua regia, as before, and free acid driven off, care being taken that no yellow powder is formed; if it is, by too much heat, a drop or two of acid must be added to redissolve it. This solution should be largely diluted and cyanide of potassium added, as long as any precipitate is formed. This is the cyanide, a lemon-yellow powder, which only requires to be separated from the solution, washed, and dissolved in cyanide of potassium. These are the usual instructions, but I advise a little further proceeding to avoid any risk of loss of gold by not hitting the exact point of precipitation. Add a trifle too much cyanide of potassium so as to insure complete conversion and redissolving of a little. Filter off the cyanide formed, and to the solution add sulphuric acid till it gives an acid reaction, and filter off after standing for some hours. Even then there is risk of the alkaline salts dissolving some little gold, but this may be recovered by setting the solution aside with some scraps of zinc, which will throw down any gold so dissolved.

In dissolving common gold there is often found a residue which obstinately resists solution, yet retains the form and workmanship of the original article; this is the silver of the alloy formed into a dense chloride.

The chloride of gold solution may, if preferred, be neutralized with caustic soda or potash (not carbonate) until it is decidedly alkaline, and then either cyanide of potassium may be added, or hydrocyanic acid distilled into it to throw down the cyanide of gold. This solution is, however, very apt to retain gold in solution with the residuary alkaline salts. If ammonia is used instead of the fixed alkalies, a precipitate is formed which is fulminate of gold, and must not be dried, as it becomes violently explosive.

720. SPOILT SOLUTIONS.—These should be treated as described for silver, § 717, but the resulting cyanide, which will probably contain other metals, should be dried, mixed with its weight of litharge, and fused. The residue, after washing, is placed in excess of nitric acid, which will dissolve out the lead, &c., and leave the gold pure.

721. GILDING.—This process is much more rapid than any of the others, as a few minutes is usually enough to give a good deposit; this is due to the high equivalent 197, so that the same current deposits nearly twice as much as it would of silver, and more than six times as much as it would of copper. Gold has also very great covering properties, and a much thinner film gives a better appearance and protection than a similar thickness of other metals would. The usual difficulty indeed is that the work is done too fast. Small battery power is needed, a single Smee having sufficient force for small articles; but with large surfaces and especially when a deep colour is desired, two Groves may be used; the point to be aimed at is to have the E M F just below the point at which gas appears on the objects.

Small objects may be gilt together in numbers by putting into an earthenware basket with a connecting wire to some of them, and shaking about in the solution, so as to expose fresh surfaces continually.

722. HEAT IN GILDING.—The solution is to be heated in a glass or enamelled iron vessel to 130°–180° Fahr. The warmer the solution, the darker the colour of the gold, which is to be controlled by regulating the battery power and the heat. The anode should have the same surface as the object, and should be fine gold; the object should be kept in constant motion, and if the colour is too dark, its distance from the anode increased.

Gilding is one of the most difficult processes to teach; its variations are so great that only personal experience can be relied on, as the colour will pass from pale to dark with very slight changes in the heat, or with different degrees of motion.

When the solution is to be set aside, water should be added to replace that evaporated off by the heat; and the free cyanide, if needed, should be added at the same time.

723. *Green gold* deposit is produced by adding cyanide of silver to the solution, or working it from a silver anode till the desired tint is obtained.

Red gold is obtained in the same way by the use of copper.

In working these solutions anodes of alloys of the proper quality should be used, or separate anodes as in § 686.

724. *The strength of the solution* varies greatly under work owing to the actions referred to § 684, and to the fact that cyanide of potassium dissolves gold pretty freely while hot; therefore, in addition to the solvent action of the current on the anode there is this direct chemical action on both anode and the deposited gold. Therefore the deposit may at times represent little more than three-fourths of the gold taken from the anode, and therefore the solution tends to be enriched and the free cyanide to be used up. This, however, is met by using smaller anodes, and the usual tendency in working is to impoverish the solution by economizing the costly anode.

The *colour of the anode* is a very sensitive test of the state of the solution, and immediately shows whether the free cyanide is deficient, by becoming foxy; on the other hand it ought not to become bright, but be of a clear dead yellow.

725. *Finishing* is effected precisely as described for silver.

Colouring.—If the colour is bad it may be made rich by the following mixture: One part each of alum, sulphate of zinc, and common salt, and two parts of saltpetre are mixed in water into a paste, which is to be smeared over the articles, which are then placed on an iron plate upon a clear fire, heated, and thrown into cold water. A bad colour in silver may be remedied with borax applied and similarly treated till it fuses. Articles united with soft solder cannot be treated by these processes.

726. PLATING IRON AND STEEL.—For some reason, difficult to understand, it is impossible to obtain an adherent coating of either silver or gold directly upon iron or steel, no matter how perfectly the surface may have been cleaned. It is therefore customary to deposit first a mere film of copper from an alkaline solution, as previously described. A film of mercury would have advantages over that of copper, for the same reasons that such a film is frequently used upon even copper or brass to secure a more perfect union between the metals. But iron resists the union with mercury as well as with silver and gold, and it is very difficult to coat its surface with a perfectly even homogeneous amalgam, though many processes have been suggested

and said to be successful. That which I have found best consists of a mixture in equivalent proportions of the nitrates of silver and mercury, in quantities represented by about 50 gr. of each metal to a pint of solution. The metals are to be separately dissolved in just sufficient nitric acid, the mercury in dilute and cold acid, and then mixed, sufficient free nitric acid being kept in the solution to feebly act upon iron when plunged in it. The metal leaves this solution covered with a dark powder, which, on lightly brushing under water, gives place to a bright surface. The object should be at once placed in the silvering solution, and, when a coating is seen to be formed, it should be removed, washed, dried, and heated to about 400° Fahr.: its surface should be then scratch-brushed, and the article replaced in the silvering solution till a sufficient coating has been deposited. Iron and steel may also be amalgamated by rubbing with sodium amalgam after well cleaning, and may then be plated in the same way as other metals.

727. NICKEL PLATING.—This process has come into much use in the last few years, and bids fair to be very largely employed for many articles in common use. There is, however, much misconception as to the purpose and advantages of a coat of nickel. It takes a very brilliant polish of a bluish tint, and the hardness of the metal enables it to retain that polish much longer than silver does; then, unlike silver, it is not affected by sulphuretted hydrogen, and does not blacken with the gases given off from burning coal or gas; it is therefore admirably adapted for such purposes as shop-fittings, and particularly scales and weights, which would merely require to be washed or wiped in order to keep them clean; and for window-frames and door-plates, which would long retain their beauty with little labour. But it is often stated that nickel resists acids, and this is not the case, for all the ordinary acids dissolve it freely; it is therefore not suited for instruments to be used in chemical laboratories, or where acid fumes prevail; nor is it adapted for lining to vessels used for cookery, as silver is. However, although nickel is very closely allied to iron in its chemical properties, it does not rust in the air, though it takes a yellow tarnish which may, however, often be due to an action on the underlying metal through the pores of the coating.

728. *Nickel Solution.*—Nickel may be deposited from almost any of its solutions, but compounds of the metal with alkalies work better than the plain salts of nickel. The *cyanide of nickel* and potassium works well and is said to be improved by the addition of common salt. The *chloride of nickel and ammonium* is also

a good solution, and may be made by passing a current from a nickel anode into a strong solution of ammonium chloride, as described for silver, § 702. The compound of nickel and ammonia with sulphuric acid is, however, the best, and it has two forms. The *ammonio-sulphate* may be prepared by dissolving crystals of nickle sulphate in liquid ammonia forming a dark blue solution; it cannot be recommended because it constantly loses ammonia. The sulphate of nickel forms $NiSO_4 + 7 H_2O$ 155 + 126 = 281, green rhombic prisms containing 7 atoms of water. Sulphate of ammonia $(NH_4)_2 SO_4 = 132$ has the property of replacing one of these atoms of water and forming the double crystal $NiSO_4 (NH_4)_2 SO_4 + 6 H_2O = 395$, a saturated solution of which, with a little water added to diminish the tendency to crystallize, is the solution to be used.

The sulphate can be made by dissolving crude nickel in the acid, and purifying it from other metals, but it is unnecessary to give the process because the double salt is an article of commerce, and is better bought than made. The double salt crystallizes out on addition of sulphate of ammonia in excess to the sulphate of nickel, as the double sulphate, though freely soluble in water, is insoluble in the sulphate of ammonia solution, which will, therefore, throw it down out of old solutions if desired.

This solution has a great legal and commercial interest, as it has been the subject of prolonged litigation,. with the final result of proving that it is dangerous for people to attempt to appropriate common knowledge. The use of the double sulphate was known long ago, and mentioned in Smee's Electro-Metallurgy; again, in 1855, Dr. Gore described its use: but yet a patent was taken out in 1869 by Dr. Adams, in which nothing was added to existing knowledge, except the statement that the total absence of potash and soda was essential, which statement, however, is not correct. Yet the law allowed that question to be battled through the courts at enormous costs, till at last it was established that the patent had nothing in it. One curious incident of that litigation was that Mr. Weston took out a patent for a nickel solution containing boracic acid, to be neutralized with caustic soda: the object of this "invention" was probably, not actually to work that "improvement," but to forcibly demonstrate that the very things on which the litigated patent hinged, and the absence of which was said to be essential, could be used without injury to the process.

729. Depositing Nickel.—The real difficulty lies, not in the selection of a solution, but in the management of the operation, for nickel is different from any of the ordinary metals hitherto

described, in that its deposit is always accompanied by a considerable evolution of hydrogen gas; this is, of course, pure waste of power, and the object to be aimed at is to get as little gas and as much nickel as possible. Another consequence is, that the deposit is apt to contain gas, and therefore to be porous or flaky, in which case the coating tends (as soon as it reaches a moderate thickness) to split and curl up, and separate in brilliant films. To prevent this, the solution should be strong, and the battery power carefully adjusted to the work doing. A powerful battery is required at first starting, such as two or three Bunsens in series, but as soon as a complete coating is obtained, economy and good working both require less force to be exerted; for the main deposit a single Smee cell is sufficient, but its size must correspond to that of the objects to be coated, and the resistance of the depositing cell must be controlled by means of ample anode surface, fully as large as the objects. The solution should have a sp. gr. of 1·030, and must be kept neutral or very slightly alkaline by addition of ammonia when necessary, this being the most essential detail of the process: the tendency of all ammoniacal salts is to become acid by losing ammonia, and any free acid thus produced prevents metal from depositing, or redissolves it in the act of depositing, giving off hydrogen in its place.

Sulphate of nickel may be used in a single cell process exactly as in the case of copper, but it is an exceedingly wasteful plan, as the nickel salt passes through the porous cell, and is reduced upon the zinc plate, just as copper is.

The surface of the nickel deposit, when good, presents a very peculiar appearance; it is not bright—a bright deposit will usually peel off, but of a dull yellowish colour; after removal and washing it has to be worked up to brightness by the usual processes of polishing.

730. *Anodes of cast nickel* are now to be readily purchased; at one time the metal went to a high price, owing to the demand and the difficulty of casting it, when pure; but large supplies of ore have been discovered in New Caledonia and in America, and the manufacture being greatly improved, the metal is now cheap; it melts easily when a little tin is added, and it has been discovered of late that a small addition of phosphorus also causes it to melt freely: other improvements have been made so that it can even be rolled into sheet metal and welded upon sheets of iron.

731. The following particulars of apparatus on the factory scale may prove useful:

The *depositing cell* contains about 70 gallons of liquid, in which the double sulphate is dissolved at the rate of three-quarters of a pound per gallon: it is a wooden tank, lined with asphaltum cement, 5 feet 6 inches long, 2 feet wide, and 14 inches deep.

The *battery* is a cell containing about 10 gallons of liquid, which is a very dilute sulphuric acid (20 ounces to the charge is named), fitted with six amalgamated zinc plates 9 × 10 inches with six equal sized carbon plates arranged alternately between the zincs.

About 6 inches square of anode surface is used per gallon of solution, and the anode surface is always kept in excess of that to be plated. In some cases batteries are used consisting of two cells in series, similar to that described, the plates in each cell being connected so as to act as one plate of each kind; but the dynamo-machine is rapidly superseding the battery for all work of electro-deposition on the large scale.

732. IRON DEPOSITING.—Iron has very great chemical resemblances to nickel, and most of the remarks made upon the latter metal apply also to iron. The solutions are corresponding ones, in which iron takes the place of nickel, but owing to the tendency of iron salts to pass into a higher state of oxidation, they spoil rapidly. Hydrogen is given off also, and it would appear that the corresponding oxygen appears at the anode, unites there with the iron, and thus tends to the production of basic salts. For these reasons, in the case of iron, the double chloride of iron and ammonia appears to be more advantageous than the sulphate. To produce this, dissolve clean iron wire in hydrochloric acid, using heat at the close, and having iron in excess to prevent the formation of perchloride; for every 58 grs. of iron dissolved add 53·5 grs. of ammonium chloride to the solution. I have found that the addition of a proportion of glycerine to the solution diminishes its tendency to spoil. No deposit can be obtained from a solution of a ferric salt; in these the action takes the form of a generation of hydrogen at the cathode, which reduces the salt to the ferrous condition; at the anode, meanwhile, iron is dissolved by the acid set free until a neutral ferrous solution is produced. In consequence of this, an iron solution which is spoilt either by action of the air or by generation of basic salts, may be renovated by adding the proper acid, and, if needed, heating it till it becomes clear, and passing current from an iron anode. Of course there must also be a proportionate addition of ammonium chloride.

A good working solution may also be made by passing current from an iron anode into a solution of 1 part sal-ammoniac in 10 of water. It is said also, that carbonate of ammonia, 1½ lb. per gallon of water, will produce a good solution in this manner.

The deposit of iron is likely to have important scientific uses, as in examining the laws of magnetism, but it would not seem likely to have extensive practical application. Its principal utility is likely to be in the same direction in which it has been used for some years—viz. for printing purposes. It has been used to give what is called a "steel face" to copper plates, by depositing on them a thin film of hard crystalline iron which does not seriously affect the fine lines of engraving, but wears much longer than copper, and when defaced, can be dissolved by acids and renewed, without the plate itself being subjected to wear. It takes the ink well also, and will work with some inks, such as vermilion, which are useless with copper. It would probably answer well, also, for facing to ordinary type.

I have been informed, on what I believe to be good authority, that iron deposits beautifully, although accompanied with torrents of gas, with a battery of ten or twelve Bunsens in series, but I have not myself tried anything beyond two or three Smees.

733. PLATINUM.—This is an exceedingly difficult metal to deposit; in fact, although some writers say that it is to be done, it is very doubtful if a reguline film of tough metal has ever been obtained. The deposit is highly crystalline and brittle at its best, and tends very strongly to pass into the state of black powder. It is commonly stated that a very feeble battery is required, but this is not the case: on the contrary, it requires a force equal to four Smees in series, in order to overcome the great resistance of the liquids, and to compensate for the fact that there is no action on the anode; the platinum, therefore, is wholly derived from the solution, and must be replaced as chloride; this non-action of chlorine, even nascent, and in the electric circuit, is very difficult to understand, because platinum is chemically dissolved by chlorine, which unites with it readily as salts. A small "current," or rather small density of current, is required in order to prevent undue generation of gas and black deposit. I have found that a "density" of ·2 is the utmost current to be used.

The equivalent of platinum deposited is variable, owing to gas being generated. I have obtained from 44 to 48; theoretically it is 49·3 corresponding to one equivalent of chlorine, owing to all these solutions being of the platinic series.

A sound deposit of platinum would be very valuable for chemical purposes, but I do not think a trustworthy one can be obtained, which would be a protection to the metal beneath. But a thin deposit of highly crystalline platinum, such as may be obtained from § 736, would be more valuable for use in Smee batteries, upon silver, than the ordinary black powder, though it would be more costly at first.

734. Platinic chloride, $PtCl_2$ on the equivalent notation, or $PtCl_4$ on the atomic, is the basis of all the solutions of platinum. Its preparation requires some precautions, as it must not be heated at any time beyond the heat of the water-bath, or a change takes place which is not correctly stated in the text-books. They say that platinous chloride is produced, which will redissolve in excess of acid. I have found that over-heating, even with great excess of acid, turns the solution a dark olive instead of clear yellow (or red, if iridium is present), and that a black powder is formed which cannot be redissolved without drying and heating to red: it may be that this is due to the other metals usually accompanying platinum. Platinum left in a bottle with aqua regia (1 nitric and 3 hydrochloric acid) will dissolve in time, but the process is a very long one; heating in a water-bath hastens it; it should then be evaporated to dryness in the bath, dissolved in a little water, and if desired left to crystallize. This solution may be used to deposit from, but it requires very great care.

735. *Sodio Platinic Chloride* is obtained by adding 1 equivalent of common salt (58·5) to 1 equivalent of platinic chloride (169·5), which corresponds to 98·5 of platinum in solution: it may be crystallized as a yellow salt. This deposits more easily than the chloride.

736. A still better solution is made by adding to the foregoing about 4 equivalents (63 × 4 = 252) of oxalic acid, and then rendering the solution strongly alkaline with caustic soda. This in fact is the best solution I have tried. A similar one may be made from the yellow precipitate formed by ammonium or potassium chloride with platinic chloride. These precipitates are soluble in oxalic acid (a fact not noticed in the text-books, so far as I know, or in Storer's dictionary of solubilities); more of the acid is required, however, and the ammonia precipitate requires boiling. The sodium form is however preferable, as most stable.

737. Bœttger says, that with fresh ammonio platinum chloride dissolved in concentrated solution of citrate of soda, forming a deep orange solution very rich in platinum, two Bunsen's cells give a lustrous homogeneous deposit.

738. Roseleur recommends 10 parts of platinum converted into platinic chloride, dissolved in 500 parts water; 100 parts

crystallized phosphate of ammonia in 500 parts water; these two being stirred together a precipitate is formed: 500 parts of crystallized phosphate of soda dissolved in 1000 of water are now added and the whole boiled as long as ammonia is given off and until the liquid has an acid reaction. The solution is to be used hot, with a strong battery.

739. ALUMINIUM.—The depositing of this metal would be a process of great value in the arts. Several such have been published, and some patented, but none is of any practical value. In one case it is stated that a solution of alumina mixed with cyanide of potassium decomposes with six Bunsens or ten Smees. This statement is strictly true: it does decompose, only, unfortunately, it does not deposit aluminium, but simply gives off hydrogen. I spent a good deal of time and trouble over this, till I satisfied myself that cyanogen will not unite (as a cyanide) with aluminium. In another book (a good one, too) a process is given which is essentially one for obtaining a solution of sulphate or chloride of aluminium, and it is stated that from this a fine white deposit of aluminium can be obtained. It may be so, but all I can say is, I cannot obtain it, nor can I find that any one has as yet succeeded in effecting a deposit; all the solutions I have tried, acid, neutral, and alkaline, decompose and give off gas, but refuse to deposit metal. I believe, however, that aluminium may be more readily deposited in alloy with other metals, and with great advantage.

Aluminium may be reduced from its chloride by means of electricity, as a source of the metal, however, if the chloride contained in a crucible is kept in fusion by heat while the current passes, a carbon pole with nicks cut into it being used to receive the reduced metal. Aluminium may be obtained from *Cryolite*, a natural double fluoride of aluminium and sodium, by this process.

740. *Organic acids* have peculiar relations to metals, and their presence often brings about great modifications of chemical actions. This has been found of service in electro-metallurgy and offers a prospect of many new ones.

Cast-iron and steel have been coated with copper on the large scale, for many years, as for lamp-posts, statues, &c., by Weil's solution, which is made thus, 150 parts of Rochelle salt (tartrate of soda and potash) are dissolved in 1000 parts of water; 80 parts of soda-lime containing 50 or 60 per cent. of caustic soda, and 35 parts of sulphate of copper, are added. The lime removes the sulphuric acid and the solution remains a strongly alkaline one. This solution may be used with a battery, but is best worked by single cell process, either by attaching zinc to the objects or by using a porous vessel containing caustic soda for the zinc. As the copper is removed an equivalent proportion of oxide of copper should be added.

Similar solutions can be used with nickel and other metals, and other organic acids besides tartaric acid have similar effects; see § 742.

741. DEPOSITING ALLOYS.—It is supposed by many, and the idea is supported by many indirect statements in the books, that metals deposited by electrolysis are absolutely pure; but this is a great mistake, as far as the principle is concerned. It is true that the current exercises an elective influence when salts of several metals are in company, as explained, § 614; this election depends upon the fact that each chemical compound requires a definite force to break it up, and therefore, as a rule, the one most easily decomposed will deposit its metal in preference to the others; but if the force be sufficient, all will be decomposed, and a mixture of metals will come down. The solution also exerts a selective influence on the materials of the anode; hence pure copper can be obtained in a solution of the sulphate from an impure plate, because the sulphuric acid refuses to dissolve the carbon, lead, tin, &c., which form a dirty coating over the plate after a time, while any zinc and iron passing into solution require so much more force to decompose that they remain in solution; but pure copper would not be so easily obtained from a solution of chloride, nitrate, or acetate, as these would carry over the easily reducible metals, which would deposit even sooner than the copper.

742. But the object to be attained in depositing alloys is to be able to secure a definite proportion of a given quality, and as to the mode of effecting this very little is really known. The subject is of so much interest, and may have so much importance, that I depart from my usual practice of stating nothing that I have not thoroughly tested. In this case I propose to give the particulars of various solutions published for depositing brass and bronze, and then to furnish a statement of the principles necessary to be attended to in any attempts to devise solutions and modes of working.

1. De Salzede.—Dissolve the cyanide of potassium in 120 parts of the water, then in the remainder dissolve the salts of potash, zinc, copper, and ammonia, raising the heat to about 150° Fahr., adding each salt as the first is dissolved, and stirring well; then mix, and allow to stand a few days.

2. De Salzede, prepared in same way as 1.

Both are worked with brass anode, and a battery of two Bunsen's cells giving a full current.

The quantities are proportional, grains or ounces, &c.:

TABLE XXV.—BRASSING SOLUTIONS.

	1	2	3	4	5	6	7	8
Water	5000	5000	1280	50	400	160	10	2000
Copper	..	..	..	..	..	..	..	..
„ chloride	25	15	..	..	2	..	..	10
„ acetate	..	..	5	10	..	..	..	..
„ cyanide	..	..	..	..	..	2	..	..
Zinc sulphate	48	35	10	..	4	..	..	20
„ acetate	..	..	..	1	..	..	..	..
„ cyanide	..	..	..	..	..	1	..	..
Potassium cyanide ..	12	50	8	*	..	16	1	24
„ carbonate ..	610	500	72	..	50	..	..	160
„ acetate ..	..	..	..	10	..	..	..	..
Ammonia liquid ..	..	..	40	..	..	..	..	*
„ carbonate ..	..	..	..	..	..	16	1	..
„ nitrate ..	305	..	..	..	25	..	..	..

* Sufficient to effect the purpose.

Bronze may be deposited by substituting chloride of tin for the sulphate of zinc—25 parts in 1, and 12 in 2, working at a temperature not exceeding 97°.

3. Divide the water into two parts, and one of these into four parts, and dissolve the salts. 1, the copper, and add half the ammonia; 2, the zinc, at about 180° Fahr., and the rest of the ammonia; 3, the potash; 4, the cyanide of potassium in hot water. Then mix 1 and 2, and add 3 and then 4, stirring well; then add the remaining half of the water.

Work with brass anode and full battery power, adding ammonia and cyanide of potassium when required.

4. Russell and Woolrich.—Dissolve the salts, and add sufficient cyanide of potassium to redissolve the precipitate formed and be somewhat in excess. Worked with brass anode.

5. Dissolve separately and mix.

6. Dissolve and mix, adding the cyanide last.

7. This is to be prepared by the battery process, the solution being made and kept at 150°. A large brass anode and a small cathode are connected to a battery, and current passed till the solution deposits freely.

8. Brunell.—Dissolve separately, mix the copper and zinc solutions each with part of the potash, then with ammonia enough to redissolve all precipitate, and add the cyanide solu-

tion. To be worked with large brass anode and two or more Bunsen's cells, adding ammonia and cyanide as required.

It is stated by Watts that the solutions 3, 7, and 8, containing ammonia, work the best, because they dissolve the zinc from the anode more freely; and that whenever a white deposit forms on the anode, free ammonia should be added.

No. 6, which is Morris and Johnson's, is spoken of very highly by some as giving good deposits capable of varying proportions. It is to be worked hot, and requires strong battery power, giving off abundant gas while working.

Weil's solution, § 740, can be used to deposit bronze by adding stannate of soda, or chloride of tin dissolved in caustic soda; or brass by a similar addition of zinc dissolved by caustic soda, and so on with other metals as desired.

743. *Principles.*—(1) The object to be attained is the deposit of definite proportionate weights of two or more metals: but as the current knows nothing about weights, but measures its work by equivalents, the proportions by weight desired must be reduced to equivalent proportions, by dividing the weight by the electric equivalent given in the table, p. 319. Thus, a brass is required containing 64 copper to 36 zinc; $64 \div 31 \cdot 75 = 2 \cdot 02$ and $36 \div 32 \cdot 6 = 1 \cdot 08$ gives the proportion in which the current must divide itself between the salts of copper and zinc.

(2) The solution need not contain the two metals in either of the two proportions, weight, or equivalent; the relative degree can have no fixed law, as it must depend on several conditions, and mainly upon a combined consideration of the facility with which the two salts decompose, and the equivalent proportion required to be decomposed.

(3) Incompatible salts cannot be joined in one solution (that is to say, salts which exchange their constituents or throw down a portion as insoluble), unless another ingredient is to be added which will redissolve the precipitate; this latter is often the case when ammonia or cyanide of potassium is to be added, more especially ammonia. In such cases, however, it must be ascertained that these new conditions do not alter the relative conductivity or decomposability of the various metals in solution.

(4) It is of the utmost importance that the metals of which the alloy consists should not have any strong electric relations to each other in the solution to be used. It must be remembered that what is called the electric order of metals is a pure delusion, unless taken in a particular solution, for a metal may be positive to another metal in one solution and negative to it in another,

as this depends on the relative affinities of the metals to the other radicals.

(5) It is *desirable* that the several salts should have nearly the same electric resistance, or that these resistances (which partly depend upon the quantity of each salt dissolved) should be proportioned to the relative currents required (see 1); but this is not essential.

(6) It is *essential* that the battery power be balanced against the decomposability of the several salts. This is distinct from their resistance. Each chemical combination needs a fixed force to decompose it, and this is effected by maintaining a sufficient electric tension at the plates to effect it. This may be called the *specific molecular resistance*, set up at the cathode only, while the electric resistance lies in the space between the plates. If there is a great difference between the specific molecular resistance of the different salts, the current will tend to reduce the lowest only, and that perhaps in a powdery state; in such cases the only remedy is to have only a sufficiency of the weaker salt present to supply the required deposit, thus forcing the current to act sufficiently upon the more resisting salt. See § 607.

744. Practical Suggestions.—There is only one mode of satisfactorily examining all these points, and this is to test each one by means of a galvanometer which will measure the actions on a definite system. Vessels of the same size should be used for comparing different solutions, and plates of the different metals and also of the desired alloy provided, all of exactly the same size, such as a square inch or 1 × 2, with such an arrangement as will insure always the same distance between them; then, to ascertain if the condition 4 is fulfilled, the two metals are connected to the galvanometer as if they were battery-plates, to see if a current of notable amount is set up. The same arrangement tests condition 5 by using two plates of the same metal as the solution; the greater the resistance, the less current will pass from a constant battery. Condition 6 can be tested at the same time by observing how many cells of the battery are required to force a given current through, but this test will be only approximate as the resistance affects it; still, it will give practical information.

Care must be taken that there is sufficient free solvent and also water to freely dissolve the anode and keep it clean, as sometimes one metal will dissolve more readily than the other. This, as well as other points, will be ascertained in the experimental vessel by testing with separate anodes of the various metals; they ought all to allow the same current to pass under the same conditions, because this depends wholly on the action of the anode.

It will be observed that the object in these experiments is to isolate and vary one particular fact at a time and measure its influence.

745. **Anodes.**—These should usually be of the kind to be deposited, so as to maintain the solution uniform. But it may be desirable to use several plates of the separate metals. Here, I think, may be found a principle in alloy depositing which has not yet been employed—viz. to use a separate battery for each anode, so as to vary the force exerted on each metal as necessary; by this means both conditions may be controlled, exactly the proper proportions of each metal may be forced into the solution, and the required tension may be exerted upon each. It is true that the metals are not transferred by the current itself, and therefore the different currents will not select at the cathode their own particular metal, but a sufficient electric force for each will be present at the cathode, and the due utilizing of it must be provided for by attention to the other conditions explained. A similar result may be attained with one battery sufficiently powerful, by leading separate connections from the positive pole to each anode, and interposing resistances so as to control the current to each; but distinct batteries would be best. Of course, all the negative poles would go to the object to be deposited on, the cathode; it would also be desirable to have a galvanometer in the circuit of each anode to secure accuracy.

CHAPTER XI.

TERRESTRIAL ELECTRICITY.

746. **Earth Currents.**—The telegraph lines have revealed the existence of currents due to causes independent of the batteries, varying in direction and also in strength; they frequently render it impossible to send messages along lines by means of the usual earth plates, but necessitate a return wire circuit, proving that the E M F exists at the earth plates, not in the wires. It has also been found that lines having east and west direction are more disturbed than those having a north and south direction. It is not necessary to go fully into this subject, as to which knowledge is imperfect, though growing, but the following particulars are derived from various communications to the Society of Telegraphic Engineers.

747. The usual effect of the earth currents, is that of a low E M F continually fluctuating in intensity while nearly constant in direction, which may be considered the *normal* action; there are, however, reversals of direction of the *current*, though it seldom changes its line of conduction; and at times there are great and rapid changes, both of force and direction, which are called *magnetic storms.*

748. *A general cause produces the currents;* they are not due to local conditions at the two points connected by the wires, for a comparison of observations taken at many different parts shows simultaneous variations.

749. The general *direction of the currents*, that is to say, their course, appears to be along the lines of magnetic latitude, those of equal declination, or north-east and south-west in England; this of course must be the case if the currents and the earth's magnetism are in any way connected together. Eliminating the various disturbing causes, it would appear that the proper direction, that is, the *normal current follows the sun:* that is to say, it corresponds with Fig. 36, p. 97, and with Fig. 35, constituting the earth a magnet with its south pole pointing north, which is really the case, if we compare the earth with one of our magnets.

750. The E M F corresponding to the currents is usually about volt ·03 per mile: during a general disturbance in January 1881, it rose to volt ·5 per mile, and at the same time an unusual disturbance occurred in the activity of the sun; in other cases a force of two volts per mile has been observed, and it is said to have risen as high as 6 volts.

The E M F shown in submarine cables is much lower than that of land lines; rarely exceeding 1 or 2 volts for the whole cable, but it does not follow from this that it is really lower in the ocean than in the earth: the resistance of the sea is practically nothing; the line in which the earth current is set up is really a mere derived circuit from the natural one; therefore the current traversing the conductor will of course be proportional to these resistances and must needs be lower in cables traversing the sea than in lines dividing with the earth.

751. The E M F has *periodic variations:* it has a *diurnal* variation, with maxima about 10 A.M. and 4 P.M., also after midnight, and a minimum near sunrise: information on this point is scanty and not to be relied on, but it indicates a connection with the solar heat corresponding to the magnetic variation, § 318. It also shows that we must regard the earth's magnetism, not as consisting of one definite homogeneous line, such as would be due to a permanent bar magnet passing through the earth, or to one suspended within the earth's interior, but rather as due to a series of independent bars or lines forming a shell, each line of which has its own local influences and independent motions, besides combining to produce the total effect of the earth's magnetism.

752. *Magnetic storms* are also periodic and related to solar activity, the maxima and minima of frequency coinciding with the 11-year cycle of sun-spots, and special storms have often been found to occur in company with the outbreak of large spots on the sun; see § 142. 1877 was a year of very slight disturbance.

753. It would appear from observations of Mr. A. J. S. Adams that the *position of the moon* as regards the earth has some important influence upon the normal current, though we may not adopt all the theories on the subject which he examined in a paper published vol. x. p. 34, 'Journal of Society of Telegraphic Engineers' for 1881.

754. The *magnetic variations*, § 318, indicate that the presence and position of the sun is acting, and we have two modes of action to consider: 1. the thermo-electric; we have two points of growing and diminishing heat at opposite sides of the earth, and points of maximum and minimum heat between them, and

these points travelling round the earth. 2. The magnetic: variation of temperature modifies magnetic capacity and intensity, § 138; all the materials of the earth are magnetic, and therefore the heat of the sun must produce a state of lower magnetism travelling around the earth, with an electric current as a consequence. All these no doubt play their respective parts in the total effect.

755. As the magnetic polarity and intensity of the earth undergo constant changes at each locality, which are tantamount to moving a magnet across the normal earth currents, it follows that we must expect a variation in these currents themselves; but which is really the cause and which is effect we must wait to learn.

756. SUPPOSED STATIC CHARGES.—From observations taken at Kew and Greenwich it appears that no changes in the electrical conditions of the atmosphere are found to accompany the magnetic storms, a circumstance of great significance to any theories based upon supposed static charges on the earth.

757. In connection with this subject the theory of Messrs. Ayrton and Perry as to the source of terrestrial magnetism should be mentioned. They attributed it to a static charge of electricity, which Professor Rowland shows acts like a current if it be moved around a body: they calculated this charge as 10^7 micro-farads and that it would require a difference of potential of some 54 million volts between earth and space.

758. Taking the value of atmospheric potential estimated by Sir W. Thomson, § 765, they calculate that "the probable *actual* charge therefore equals 1364×10^{12} C.G.S. units or about 14 times as great as would be necessary to produce the earth's magnetic moment if the earth were solid iron." It is worth while to note these statements, because the paper in which the theory was set forth is a very elaborate mathematical calculation, and a very striking illustration of the manner in which mathematicians can *prove* anything they like. All that is necessary is the little phrase we so commonly meet in these cases, "if we assume." Now this theory assumes first that there is a static charge of electricity on the earth, for which there is not a particle of evidence; it calculates the potential as above of a charging source, one pole to earth and the other to all the bodies in space, the only way by which a charge would be got at all, and naturally the only conceivable source would be the sun, and the result would be opposite + and − charges on the sun and the planets; even a mathematician in search of a theory would scarcely venture to assume that the earth is the source of the force; yet Professor Perry on another occasion

says "it is very probable the charges of all bodies of the solar system have the same sign," though how such charges are conceivable is yet to be explained.

759. However, Prof. Rowland, by another calculation, showed that the supposed charge would only account for 1-640,000th part of the earth's magnetism, so that Messrs. Ayrton and Perry have abandoned this theory as to the total magnetism, but still maintain it as to 1-1000th of the total, in order to account for the fluctuations of the earth's magnetism, and so for the production of earth-currents.

By another elaborate calculation, Prof. Rowland shows that if the moon were electrified to an equal potential to that required by the theory, the repulsion set up would drive it off into space, which however Messrs. A. and P. find, would result in only one-fourteenth of that mechanical effort. He also showed that the effect of the supposed charge would be to burst the earth up altogether.

It is rather strange that it did not occur to some one to "assume" that this disruptive tendency was counterbalanced by the magnetic attractions within the earth, and that earthquakes and volcanoes are consequences of temporary diminutions of the earth's magnetism, permitting partial disruption. There would be no difficulty in finding quite sufficient evidence of this to build a mathematical calculation upon, which would prove it quite as easily as it has been proved on the one hand, that the earth actually has a charge fourteen times as great as one which, on the other hand it is also proved, would break it to pieces.

760. Cosmical Electricity.—Electricity is a favourite resort for people in want of a theory or an explanation, whether it be of comet tails, or a blight upon apple trees; they are apt to feel a sense of satisfaction in saying, "they are caused by electricity." It is natural, therefore, to think that the all-pervading force of electricity may play an important part in astronomical phenomena: there is, however, no warranty for the supposition, and when we consider that electricity is a purely molecular relation, there is good reason to believe that nothing resembling electrical action occurs across space. That energy traverses space is, of course, certain, but in which of its forms it does so, is unknown, though light appears the most probable, and magnetic induction may also bear a part. But there is no sort of evidence that anything resembling static electrical actions occurs, or that the cosmical bodies have anything in the nature of free charges of electricity.

761. The nature of electricity itself is opposed to the idea,

when we recognize (note, p. 21) that it involves two equal opposite charges connected by lines of force. Therefore, it is impossible to conceive all the bodies in space "charged with electricity of the same sign," which would involve a mutual repulsion, according to the doctrines connected with supposed free charges. But we have positive proof that opposite charges do not exist on the sun and the several planets. *If such charges existed, gravitation would not be a constant force.* The planets, as they approached each other, would have their attractions partly neutralized by electric repulsion, and this effect would vary with the mass and size of the planets, because their capacity for electricity varies as their radius, § 93 (*a*), while their masses, if constituted alike, vary as the cube of the radius. But astronomy shows that the mutual action of gravitation is directly as the masses, and is the same between the several planets as it is between them and the sun, neither of which would be the case if they were charged bodies, as the sun would have the electric attraction added to that of gravitation, while the planets would repel each other against gravitation.

762. *Clerk Maxwell's theory of light*, is that light itself is an electro-magnetic disturbance: he conceives that electro-magnetic action is transmitted across space by waves at right angles to the line of transmission, as light is; that electricity and light have the same absolute velocity and that as a consequence all true conductors of electricity are opaque. That there is a connection between light and electricity is certain from the effects of electric stress upon the transparency of substances and from the fact that the specific inductive capacity is related to the square of the index of refraction; this is a result of the theory which is approximately true for rays of great wavelength. But it may be doubted whether all the coincidences are not simply consequences of the molecular actions of both light and electricity upon matter, rather than evidences of identity of nature or action. At present the theory is only a matter of speculation, but it may ultimately become of importance in connection with the transmission of energy across space, and for that reason it is mentioned here.

763. ATMOSPHERIC ELECTRICITY.—Inasmuch as every chemical action or even mechanical disturbance of molecular arrangements sets up electrical conditions, which very often are regarded as causes when they are merely consequences (as in the phenomena of life), we might expect to find the moving and changing atmosphere in a constantly varying electrical condition, varying in fact not only in time, but at even neigh-

bouring places. We may also be certain that these changes must react upon the vital actions and sensations of all organisms influenced by them, and that the average electrical condition of any place will be an important element in its climatic qualities; but very little is as yet known on this subject.

764. The electric condition of any point in the atmosphere is observed by means of a conductor terminating at that point and brought to the same potential. This may be effected by means of living vegetables, such as grass and leaves, which are more effective than the pointed metallic conductor: it is more commonly effected by means of a flame or a roll of smouldering touch-paper at the end of the conductor: Sir W. Thomson uses a metallic cistern of water fitted with a tube from which the water continually drops: these conductors are insulated from the earth and connected to the electrometer, such as one of the pairs of the quadrant electrometer; the other pair being put to "earth" so as to indicate the "difference of potential" between the earth surface and the point of the conductor. Greater elevations may be explored by means of kites, the string of which may contain a wire: it was by such means that Franklin established the identity of lightning and electricity; but it is a dangerous experiment and more than one has lost his life in making it.

765. Sir W. Thomson found a difference of potential of 430 volts in 9 feet, or from 23 to 46 per foot, at the Isle of Arran, and 40 at Aberdeen. But we cannot legitimately deduce from this that a similar rate of increase extends to any great distance from the earth's surface.

The electrification varies, being at its highest about 8 A.M., and 8 to 9 P.M. in summer, and 10 A.M. and 6 P.M. in winter, and lowest about 3 P.M. and midnight: this really indicates that it is highest just when the greatest change of temperature occurs, and when the dew-fall and evaporation are greatest. It may interest some to know that an east wind always raises the + electrification, while rain is almost always attended with − potential in the air.

766. It should be clearly understood that this electrification is in no sense a static charge; it is simply a condition set up in the air analogous to that which exists in the glass of a Leyden jar; the surface of the earth and the air have equal + and − electric quantities distributed over them, or inasmuch as there is really no "quantity" at all on the earth surface (or, if it is considered as having a − charge its quantity varies with the thickness of the air compared with it), what is really measured is the energy stored in the "field of force" constituted by the

air space: therefore there remains nothing to act towards external space.

767. It may be worthy of consideration whether a difference of *electric potential* exists at all in the atmosphere in ordinary conditions, or at all events whether more than a small portion of what is observed exists as such. It is most probable that a continually varying electrification is really produced by the friction of wind and of cloud masses; but it may be that the greater part of the observed effect is due to the instruments themselves; that the *charge* is potential energy, not electricity, and that the conductor of the instruments, by providing the return circuit, establishes the conditions under which the potential energy takes the form of E M F.

768. *Evaporation* from the salt-containing waters of the earth has been commonly regarded as the source of atmospheric electricity, this act being supposed to carry off + electricity and so leave the earth itself –; but the balance of evidence indicates that electricity is not developed by quiet evaporation. Those experiments which indicate its production are attended with other causes, such as chemical action upon the containing vessel, or else friction set up by rapidly issuing steam. Faraday examined this subject with his usual care, with the result that the electricity was due, not to the evaporation, but to the friction of particles of water, &c., carried by the issuing steam; he also found that the addition of various substances modified the result, an action which is traceable to changes in the surfaces of the particles of water.

769. But it is most probable that although evaporation does not directly set up difference of electric potentials, or generate "electricity," it is yet the origin of the greater part of the phenomena of atmospheric electricity. It is the great agency for storing up the *potential energy derived from the sun*, and distributing it over the earth, and the phenomena of electricity, whether in the thunder-storm or the incessant quiet changes going on, are part of the process by which the potential energy stored in the vapour is transformed into the various forms of force employed by nature.

When we consider that 1 pound of water stores (speaking only in round numbers) over 700,000 foot-lbs. of energy and that, as explained § 576, potential energy develops "electric potential" under proper conditions, we can have no difficulty in understanding where atmospheric electricity comes from.

So also the sudden changes of electric potential are intelligible if we imagine a mass of vapour as having undergone such changes as partly condense it into a cloud, a collection of minute electrified vesicles, which gradually coalesce into rain-drops; here we have conditions in which the charge is gradually accumulated upon surfaces growing smaller, therefore the potential rises until, as in the case of ordinary discharge—§§ 83, 94 (*d*)—the dielectric resistance of the air is overcome and discharge occurs as a flash of lightning, between the cloud and either another cloud, or the surface of the earth, forming the other charged part of the electrified system.

770. When a flash of lightning occurs we can conceive it as due to the transformation of the potential energy of the vapour in the air, all along the track of the flash, which is the axis of the field of force set up: this energy being thus transformed into dynamic electricity and its attendant work, the vapour condenses into water and we have the effect so commonly noticed in thunder-storms, of an instantaneous downpour of water accompanying the flash.

771. *Earthquakes and volcanic eruptions* are attended with powerful electric discharges, which are probably consequences of the mechanical energy expended, or of chemical action of water upon heated masses of earth. It is probable that further study will enable them to be foreseen by means of these actions at their earlier stages, as the grinding of the rocks will furnish indications of the disturbance going on, long before it culminates in the full action. Buried microphones transmit sound as a consequence. During the tremendous eruption of Mount Krakatow in Java, August 1883, the telephones in Singapore, 500 miles distant, were so affected that conversation was impossible and a perfect roar as of a waterfall was heard with occasional reports as of a pistol. This effect was due to action upon a short length of submerged cable, by the tremors in the earth.

In like manner telephones are affected by flashes of lightning even at a considerable distance, partly by induction on the wires, partly by variation in the magnetic intensity, as described § 128.

772. *Waterspouts and cyclones* also are electrical in character, and it is stated that Professor Douglass of Michigan has produced artificial (or imitations of) cyclones by suspending a large plate of copper by silk threads and strongly charging it with electricity which is said to hang down like a bag, and may be rendered visible by arsenious acid gas which gives it a green colour. The result is a miniature cyclone, funnel-shaped and whirling around, which, as the plate is moved over a table, picks up loose objects. The description is rather in the way of "popular science," but there may be something in it worth attention, though it would be advisable for experimentalists to

use something less poisonous than arsenious acid gas even at the risk of losing the green colour. A plate wetted with ammonia and a bottle of hydrochloric acid open below would produce suitable fumes.

773. THUNDER-STORMS.—The common conception of lightning may almost be described as a belief that there is something packed away in the clouds, which at some uncertain moment falls from them as a "thunder-bolt," or rushes out upon the earth as a discharge of "electric fluid," with destructive effects, resembling in some degree those of the bursting of a reservoir of water. The conductor is regarded as having some *attraction* for the "bolt," and also as a pipe to receive and carry off the fluid. These ideas are not only erroneous scientifically, but they are the source of many practical mistakes in the setting up of conductors, which sometimes lead to fatal results.

Those who have comprehended the principles of static electricity explained in Chapter II., will see that they are applicable to the present subject, as lightning is strictly analogous to the artificial electric discharge. They will at once understand that the discharge does not merely issue from the clouds and rush to the earth, but that the latter fulfils a function just as important as that of the clouds; the latter are indeed the "prime conductors" of nature's great electrical machine, but the force is distributed over a vast "inductive circuit," of which the air and the earth form as much a part as the clouds themselves, and the discharge is a redistribution of force all over this inductive circuit, not across the air simply.

774. The thunder-cloud is in fact to all intents a condenser plate upon which terminates the polarized chain of a circuit, and there are two varieties of thunder-storm, which depend upon the nature of the opposite condensing plate. This may be another cloud above, or at a distance from the first; then the discharges occur between the clouds themselves, and the only effect on the earth is of an inductive nature, and is usually slight; this is the case with what is called *sheet* lightning, in which the clouds are vividly illuminated, but there is no line of light visible. In the other class the surface of the earth forms the second condenser plate, the air and all bodies between the clouds and the earth are "polarized," and assume a condition analogous to that produced in the neighbourhood of an electric machine at work. Discharge at last occurs in one or more lines in which the resistance happens to be least, when the tension has risen to a degree greater than the resistance of the circuit can sustain. Very slight circumstances determine the direction of this discharge: an animal standing on the ground, a tree, the

presence of extra moisture, or a metallic vein, or a range of piping in the ground may suffice.

775. This is very evident in the case of ships at sea: they will not only draw a flash of lightning, but there is good reason to believe that they frequently cause a change in the direction of the wind itself by the electrical conditions they set up. It is a common circumstance for a squall-cloud to arise and work half round a vessel, and at last come towards it and take it aback more or less suddenly. If the path of the cloud be traced out it will be found to be of the nature of a parabola; the original motion being gradually diminished, and its direction diverted to the vessel. I have frequently seen this occur; and on one occasion a very heavy squall-cloud rose on the weather bow of a ship I was in; it crossed our course and went away to leeward, we running up nearer and nearer to its path: the cloud then stopped, rapidly returned toward us, against the wind we had, and as it reached above us, a violent change of wind occurred, the cloud threw out its charge, struck the fore and main top-gallant masts, and killed two men.

It will be easily conceived that a large vessel, with its three masts the only salient points arising from the earth's surface in the neighbourhood, must produce a great effect upon the electrical conditions around it, and that this may frequently be the cause of the sudden changes of wind experienced. To this same order belong a variety of natural phenomena, such as what sailors call St. Elmo's Fire, when the points of masts and yards are tipped with lambent flames, which resemble the common brush discharge of our machines.

776. *Ball Lightning* is of so rare occurrence, and it is so dangerous and terrifying, that trustworthy accounts are not to be readily obtained. It appears to consist of a fiery globe of a reddish tint rotating on its axis, which slowly traverses the ground, sometimes at a few feet elevation, which in some cases explodes with a loud noise and emits vivid flashes of lightning in all directions. Its truly electric nature was long doubted because nothing resembling it was seen in electric experiments. But among the many curious effects obtained by M. Planté, with his enormous secondary battery and condenser arrangement, he has met with and described something strongly resembling ball lightning. The experiment consists of two metallic conductors, one dipping into dilute acid, while the other is held a little over the acid, after first dipping in: the effect appears to consist of a kind of brush discharge through films of moisture or vapour, which form an apparent globe of fire rotating on its axis.

It appears probable that ball lightning is really a glow or brush discharge formed upon a mass of dust or vapour, and possibly connected with a small whirlwind such as is frequently seen; that this serves as a kind of focus upon which are concentrated the lines of force or induction from a moving cloud, which carries this opposite pole along the ground, and ultimately either the excitement is quietly exhausted, when the ball disappears, or it rises to the point of violent discharge. Many of the accounts of ball lightning indicate that the balls form in low and moist spots, and often in connection with fogs.

777. In the true thunder-storm the cloud consists of a series of layers or zones oppositely electrified, with a similarly arranged, but opposite series on the earth beneath, the air between completing an electric circuit. Such a circuit is often extended over many miles, so that when a discharge occurs at one extremity a corresponding one in the reverse direction (sometimes called the back stroke) occurs at the other extremity, perhaps twenty miles away. The clouds themselves may be only 100 feet away, or two or three miles. Flashes of such length have indeed been measured by the angle occupied by the line of light and the period between the flash and the sound of the thunder, which together furnish the means of calculating the length of the visible flash. Several attempts have also been made to measure the time occupied by a discharge. Moving objects, when photographed by its light, appear as distinct as if stationary, but by means of revolving mirrors it has been ascertained that the actual duration of a flash is something less than 1-24,000th of a second, and recent investigations make it doubtful whether it is not even less than a millionth; its apparent duration is an effect of our own eyes, due to what is called persistence of vision, owing to which we cannot lose an impression once produced in much less than a sixth of a second, on which principle are based so many optical toys.

778. Perhaps the most complete and instructive account we have of the phenomena of a thunder-storm is that of Mr. Crosse, who set up a collecting system of wires and experimental apparatus for the purpose of investigating the facts. He says,

> "When the cloud draws near, the pith balls suspended from the conductor open wide with either + or − electricity; and when the edge of the cloud is perpendicular to the exploring wire, a slow succession of discharges takes place between the brass ball of the conductor and one of equal size carefully connected with the nearest spot of moist ground. After a number of explosions of, say − electricity, which at first may be nine or ten a minute, a cessation occurs of some seconds or minutes, as the case may be, when about an equal number of explosions of + electricity follows of similar force to the former, *indicating the passage of two*

oppositely and equally electrified zones of cloud. Then follows a second zone of — electricity, occasioning several more discharges a minute than the first pair of zones, which rate of increase appears to vary according to the size and power of the cloud. . . . When the centre of the cloud is vertical to the wire the greatest effect takes place. . . . As the cloud passes onwards the opposite portions of the zones, which first affected the wire, come into play; and the effect is weakened with each successive pair, till all dies away."

This description is consistent with the whole theory of electricity developed in these pages: it does not accord with the crude "fluid" theories, and the idea of charges of free electricity: but it does agree with the conception of electricity as a polar force setting up stresses in matter, storing up energy in those stresses until the capacity is exceeded and the energy breaks forth as heat and mechanical work.

779. *The distance of a thunder-storm* from the observer may be reckoned by the interval between seeing the flash and the first sound of the thunder, as sound travels about 1100 feet per second, which is nearly 4½ seconds per mile, while light travels practically in no time. The *duration of a peal* of thunder also gives an approximate measure of the space over which the storm extends.

780. The *real brightness* or illuminating power of lightning is vastly greater than it appears to be, because the eye takes time to receive the impression and spreads over the period of one-sixth of a second, the effect of energy actually expended in so much shorter an interval, § 777. A more just idea of the real light-giving power of the lightning flash is obtained when we reflect that this apparently fine line of light (resembling the carbon thread of the incandescent lamps) is capable of fully illuminating a wide expanse of landscape. This is thoroughly realized at sea when, in the intense darkness of the night during a tropical thunder-storm, one waits for the flash to lighten up the ship and enable one to distinguish the men and the work they are doing.

781. Lightning is not a mere line, such as it appears to the sight —indeed, that line is possibly enough only a visual impression of a spark rapidly passing along the line; but this line is only the axis, the most intense part of a large area taking part in the act of discharge: there have been frequent cases of the same flash doing injury at several points, distant 30 or 40 yards from each other: also it is observed that a number of vines (which are specially sensitive to lightning) in a vineyard may be injured by the same stroke, to as many as several hundred.

782. It is frequently stated that the bodies of those killed by lightning are marked by impressions of neighbouring objects,

and even that these are, as it were, photographed upon the skins of people who have received little injury. How far this is true is uncertain, but there are many apparently authentic accounts of such effects: it seems probable enough that any object, such as a metallic surface, which modifies the path of the current, and to some extent condenses a charge upon it and serves as a fresh centre of action, may form the outlines of its shape. But what is most commonly observed, are straggling lines which look like branches of trees, and are frequently said to be pictures of neighbouring trees. Some have thought that these marks are due to congestion of the small superficial veins: but a comparison of many drawings and photographs of such markings with similar drawings or smoke pictures of the electric discharge will leave little doubt as to the identity of the two, and convince the mind that these markings, at all events, are simply the spreading outwards of the lines of force where they entered the skin.

It is of more moment to those who are alarmed at the flashes of lightning to understand that when a flash is seen all danger from it is passed; a person struck never sees the flash, and it would appear that this death is the most instantaneous and painless which can be conceived. But there are some constitutions to whom this can give little power to resist the unnerving influence of lightning, because this is not due to mere fear, but to a direct nervous influence such as is experienced by many animals, and which many people experience in a minor degree in consequence of the electric conditions existing before a storm begins.

783. According to experiments of Mr. De la Rue, § 101, a flash of lightning 1 mile long involves an E M F of some 3 or 4 million volts, which is about 633 volts per foot or 16 times as great as the ordinary potentials observed by Sir W. Thomson, § 765. Lightning, though it be a current of electricity, does not obey the laws of Ohm; it does not distribute itself in the inverse ratio of the conductive resistances offering it a path; it will leave a conducting wire to leap across an air space offering many thousand times the resistance. There are various ways of looking at this fact. Faraday long ago pointed out that there is a tendency to *disruptive* discharge, to the mechanical work of breaking down the dielectric, which is proportional to the square of the E M F; while the tendency to *current* discharge, with which Ohm's law deals, is as the E M F simply; and with the enormous potentials of lightning, the square of the E M F may hold a more favourable relation to the inductive resistance than the E M F does to the conductive.

784. Then also the lightning discharge is of the nature of a sudden shock, and though we may say electricity has no inertia or momentum, yet the molecules of the conductor must have something of that nature, must take *some* time to get into motion, and it is quite conceivable that the resistance of the conductor is vastly greater during that period, than it is under ordinary conditions. We may compare the case to that of the candle fired at a board, which it penetrates under the force of violent impact, while it would crush up under any ordinary pressure. The practical effect is to show the importance of making the conductive resistance to lightning infinitesimally small, because any resistance in the passage to earth may result in lateral discharge.

785. The foregoing considerations as to the nature of the lightning discharge will enable us to see what are the true principles of conductors to avoid its effects. They are not intended to attract or convey a *discharge from* the clouds, although they must undoubtedly invite the discharge by setting up a line of low resistance; but their object is to supersede the condition of polarization and tension in the *space to be protected*, and therefore to diminish the likelihood and frequency of actual discharges. They do this in a twofold manner:—

(1) They practically raise the earth's surface to such a curved height as corresponds to the electric relations of the conductor and the air; not in an exact invariable form, as some suppose the protected area to assume; but still, roughly in a cone from the apex of the conductor, and of a radius perhaps equal to the height of the point, but this applies only to the rod itself; when buildings are in the included cone no law can be given, as the conditions are affected by their form, materials, and contents. Whatever the space protected may be, within it the conductor lowers or nullifies the condition of tension, transferring it to the space outside the cone, &c. (2) They react also upon the exterior space in the direction of a reversed cone, by the discharging properties of points when forming part of a polarized area, as explained, § 83. When a point connected to "earth," or the rubber of the machine, is approached towards the prime conductor, the latter cannot be charged, but a brush discharge occurs and a current is produced instead. The lightning conductor acts in the same manner; as soon as the charged cloud approaches, and would begin to set up an "inductive circuit" in the air, to the earth beneath it, a current begins to flow quietly in the conductor, the potential above it is rapidly lowered, and may not be able to accumulate sufficiently for a violent discharge, i.e. a lightning flash, at all; but if it does,

the discharge will occur through the space between the cloud and the outer area of the conductor's cone; and the conductor takes it up in the form of a momentary increase of current.

786. These principles settle conclusively all questions as to the construction of lightning conductors. Their object should be to connect to earth every portion of a building; and as this is actually possible only with metal buildings, they should connect every salient point and as much of the surface as possible, so as to extend around the building the area of low potential, or artificial "earth" surface opposed to the cloud. Chimneys require especial attention, because they are tubes lined with conducting material, containing warmer air, and if with fires, then extending a comparatively good conducting column of warm air towards the cloud and so inviting a discharge; hence it is that lightning almost always enters a house by the chimneys. All doors and windows causing currents of air should be closed during a thunder-storm.

787. The prime essential is a good connection to water, and this water in good electric connection to the mass of the surrounding earth; water and gas mains provide the best if the conductor is well secured to them; next to them is the metal shaft of a good pump, in a well constantly supplied by springs; then ponds or ditches. What is required is a large metal surface terminating the conductor, and in contact with a stratum of moist earth, so that a hole sunk into wet gravel, into which the conductor is led, and surrounded with a quantity of coke to increase its surfaces of contact, will answer, but dry clay, or rock, is not safe, and a connection to water contained in a mere cistern, as is sometimes employed, is worse than useless. This connection should, if possible, surround the building by means of rods from its various corners, either led to different earth plates, or else continued by a rod round the house to one earth connection. Every piece of metal-work about the building should be utilized, such as ridge-caps, guttering, and water pipes. These cannot be trusted as conductors because of the joints in them, which offer great resistance, and therefore prevent reduction of potential, but they will help to form a protecting network around the building, especially if strips of copper are soldered across each joint. For the same reason a connection should be led from the bottom of the down pipes from the gutters to the nearest suitable earth, though a very good, but variable earth connection is set up from these by the water itself during heavy rain. The lower parts of bell-wires may also be advantageously connected to an earth, such as the nearest gas or water pipes, as several accidents have occurred

from their having either received a direct charge through the walls, or having a violent current induced in them.

788. The terminals should be attached to all high or salient points, most particularly chimney-stacks: if these are wide and contain several chimneys, it is safer to have two points, though usually one is sufficient; but the kitchen chimney, or any one commonly used, and therefore lined with soot, and containing warm air, should be specially attended to. The points may be made of rods of 1-inch iron drawn out to a point, rising 2 or 3 feet above the building; they are better also for galvanizing. There is no advantage in any of the fancy points, patented or otherwise. The thickness of the conductor depends upon the size and height of the building. A factory chimney or church steeple should have a copper conductor of at least ½-inch section, either as a rod or as a wire-rope, well protected against injury; for smaller buildings, iron rod may be used instead of copper. In ordinary cases galvanized iron wire of about a ¼-inch diameter (such as is used for telegraphic purposes) will answer, if led separately from various salient points, and carried down the different sides of the house and connected as above described, to the guttering, &c., but for a single conductor at least ½-inch rod should be used. Solid rod is best, as it exposes least surface to rust, for it is the mass or weight of metal which conducts, *not its surface*, as some suppose; but every joint must be carefully made and soldered, to secure metallic continuity and low resistance.

789. It will be seen that conductors should never be insulated from the building, but, on the contrary, as much of the surface as possible should be connected to the conductor. Electrometers, &c., are often surrounded with a cage of wire connected to the earth or to the negative pole of the active source of electricity, in order to prevent them from being affected by external electric disturbances. That is exactly what we require to do with our buildings; an iron house well connected to earth would not only be perfectly safe, but its inmates would scarcely feel any of the effects usually produced on the nervous system by "thundery" weather, except so far as these are due to heat. The object aimed at in a lightning conductor should be to approach that condition as nearly as possible; to obtain an inclosed area within a conducting envelope provided with points and connected to earth.

790. Examination of many existing conductors shows that comparatively few afford trustworthy protection; they fail either by imperfect junctions at some part, and more commonly still by imperfect earth connection. Some people say that even

a bad conductor is better than none, as at all events it will protect the principal structure, even though explosive discharge occurs near its bottom. But this is very doubtful: § 785 will indicate that they may draw a discharge which might not otherwise occur, especially as while lowering resistance they would only imperfectly lower potential: § 783 will show also that there is no telling where the lateral discharge might occur; the presence of machinery or engine shafting might draw it in any direction into the building.

791. Conductors should undergo periodical tests, and it would be wise to provide the means of making such tests perfect; this could be done by attaching a well-insulated copper wire to the upper extremity, connecting its lower end also to the conductor by a screw, so that ordinarily it should form part of the conductor: this would enable the perfect continuity of the conductor to be tested at any time, by measuring the resistance of the conductor from the screws to its upper end, returning through the test wire.

An independent "earth" is also requisite to test the condition of the earth connection: but as the resistance would be that of these two earths, a third is requisite if it is necessary to be sure that the second is perfect, and also that it really is independent, as temporary connections made to gas or water mains might really be a more or less complete metallic circuit to the lightning conductor end itself.

Such temporary earths can be made by soaking the soil well with water and driving in an iron crowbar; the soil of a stable is well suited for obtaining good earth; or the stem of a metal pump may be used. Two such earths being provided, the resistance between them can be measured, and then that between each of them and the screw on the conductor. In the case of "earths" the resistance should be measured twice with the battery current reversed, so as to compensate for any polarization current set up by any difference at the earth plates. The actual resistance of each earth may thus be arrived at. The resistance of a good "earth" may be as low as a quarter ohm, and ought not to exceed half an ohm. The total resistance of a lightning conductor from point to earth ought to be brought to at most 1 ohm, and certainly should not exceed 2 ohms: it is, however, common to find a resistance of even several hundred ohms in conductors attached to important public buildings.

792. It may be well to explain here a subject which is a difficulty to many minds and has occasioned many questions. Faraday stated that the electricity contained in a grain of

water is equal to that in a powerful flash of lightning; some quote him as saying it is equal to that of a severe thunderstorm. Now it is evident that the potential energy of a grain of water is by p. 319 = foot-lbs. 6841 ÷ 9 = 760, and it is obviously absurd to compare this with the powers exerted by a flash of lightning: it is only equal to warming 1 pound of water 1 degree Fahrenheit, or the average work of a man during 5 minutes.

When Faraday made this statement he was beginning the study of electric quantities; volts, ampères, and ohms were then undreamed of; nothing but vague generalities had been attained to: it is therefore not to be wondered at that while he displayed his wonderful experimental powers in making comparative measurements, he compared together things having no relation. It is rather strange that while his statements are frequently requoted, their true interpretation should not be given. Before doing so it may be well to bring together the statements of Faraday and other workers in the same direction.

793. Faraday found that to decompose a grain of water required a current for 3¾ minutes capable of keeping red hot a platinum wire 1-104th of an inch in diam. We can express that intelligibly as a current of 3·13 ampères, or a quantity of 704·37 coulombs. He found that to effect the same decomposition by the machine required 800,000 charges of a Leyden battery of 15 jars, each having 184 square inches of coated glass. Each of those charges produced by 30 turns of a 50-inch plate machine was capable of killing a rat, and was equivalent, chemically, to the action of a platinum and zinc wire each one-eighteenth of an inch in diameter, immersed five-eighths of an inch in weak acidulated water for about three seconds. Weber has calculated that the charge due to 1 grain of water if placed on a cloud 1000 metres (3281 feet) above the earth, would exert an attractive force equal to 1497 tons.

794. Becquerel arrived at somewhat similar figures, and Weber compared the charge of a Leyden jar of which the static value was measured by the torsion electrometer, with the battery current producing equal effect upon a galvanometer. He found a current whose force equals the electromagnetic unit required a quantity of electricity of $155{,}370 \times 10^6$ static units per second. To decompose a milligramme of water required 106⅔ that amount (this being the ratio of the electrochemical to the electro-magnetic unit), or $16{,}573 \times 10^9$ units of electricity. Taking nine times this for an equivalent, he reckoned that on a cloud 1000 metres high, an attractive force

of 226,800 kilogrammes or 208 tons would be exerted. He also reckoned that assuming the oxygen and hydrogen atoms of this water were separately ranged upon threads 1 millimetre long, then to effect the decomposition, the threads would require to be drawn apart with a force of 147,380 kilogrammes or 145 tons.

795. Now let us translate these results into modern expressions. The current value of 1 grain of water, § 793, is 704·37 coulombs. What is the condenser which will replace Faraday's 800,000 charges? which represents 1 charge of 15,333,335 square feet, or 1 Leyden jar with a coated surface of 352 acres, which would be a moderate sized thunder-cloud, being more than half a square mile. The actual size of the condenser would depend on the potential, and starting with the unit 1 volt we require a capacity of 704·37 farads, or 704,370,000 micro-farads § 389; taking 3·5 miles of cable as the physical micro-farad we find that 1 volt, or say 1 Daniell cell, would require 2465 million miles to receive the charge, or enough to wind 1200 times round the earth and moon, or twice round the earth's orbit. Or if we take the earth's (imaginary) capacity, § 388, as 700 micro-farads, it would charge to 1 volt a million such worlds as ours, or taking the potential estimated by Messrs. Ayrton and Perry, § 757, 54 grains of water would supply the electricity they require to account for the earth's magnetism.

796. Leaving all these fantastic unrealities, let us see what is the common sense of the matter. It is simply a question of the relation of the two quantities Q and *Q* of § 576, of Q and Q^2 of § 15, or of Q and E of the ordinary formulæ, that is to say of the two functions which *together* constitute what we mean by electricity, while the word is frequently applied (as in this case) to each one of them separately: these two are Q, *quantity* or the molecular action of matter, and E, *energy*, the potential under which the molecular action occurs, the stress put on the circuit. All the ideas we have been considering depend on the imaginary, but impossible, isolation of Q; the real phenomena depend on Q × E, the matter and energy which together constitute electricity.

797. Now in the case of water, E is a potential of less than 1·5 volt, and what we have to take into account in the case of the grain of water is therefore $Q \times E \times k$, or $704 \times 1{\cdot}5 \times {\cdot}7373$, this being the constant expressing the energy in foot-lbs., which gives us just the 760 foot-lbs. which we know is the mechanical equivalent, § 792, of the grain of water. In the case of the lightning flash, the Q of which we assume to be this same grain

of water, we have a potential unknown, but which we may take to be that arrived at in § 101. Thus we have

$$704 \times 3{,}604{,}000 \times \cdot 7373 = 1{,}872{,}000{,}000 \text{ foot-lbs.}$$

This figure enables us to understand why this "grain of water" can produce such tremendous mechanical effects when concentrating this energy upon some point of high resistance in an infinitesimal fraction of a second.

The mere comparison, so often quoted, of the (quantity of) electricity in a grain of water and in lightning, is just as unmeaning as would be a comparison between a cannon-ball rolled across a table, and the same cannon-ball as it leaves the gun.

798. But the *current* of such a flash is not a small one, as is often stated: if we take the time of the discharge as 1-20,000th of a second, 704 ÷ 20,000 = 14 million ampères, a current greater than all the dynamos on earth could generate. From this it is pretty clear that no lightning conductor is ever called upon to carry such a current; either it lowers the potential, producing a steady current, and reducing the actual flash, when it occurs, to a very small one, momentarily raising the current, or it only carries a small part of the discharge which is largely distributed over surrounding space.

CHAPTER XII.

ELECTRO-MAGNETISM.

799. Throughout these pages the transmission of electric current has been regarded mainly as consisting of a breaking up and reformation of the molecules which form the polarized chain or circuit, this being the action which undoubtedly does occur in electrolysis where the action can be best examined. But no single conception will convey the whole of any scientific truth, and it has been indicated, especially in § 542, that transmission may be effected by other means (such as *rotation* of the molecules) dependent upon the same causes, for instance, the polar attractions of the molecules, which in electrolysis produce actual disruption.

800. It is indeed very difficult to conceive that the same action occurs in solid conductors like wires, as takes place in liquids, because no change whatever appears to be produced in the wires. We might indeed conceive that in solids the freed semi-molecules at each end of the wires unite with similar ones to reconstitute the metals, unchanged in physical property and form. But an experiment will prove that in solids this action does not occur: we cannot conclusively test it in simple substances such as metals, but some metallic sulphides which are true binary compounds, and which would, if fused, be electrolytes and undergo the process of breaking up, are conductors also when solid. Now I have interposed a piece of such a sulphide between two plates of silver (which has a strong affinity for sulphur), and passed current for some time: there was no formation of silver sulphide, and therefore it is clear no such action occurred in the solid sulphide as would have occurred had it been in the liquid state.

801. ROTATION OF MOLECULES. — A rotation of molecules involving a reversal of their polar arrangement will, however, fulfil all the conditions required, and in examining the relations between magnets and electric currents there will be found good reason to believe that such a rotation does actually occur in

solid conductors, and that the direction of what we call the galvanic current, that is to say, its magnetic and chemical relations, depends upon whether this rotation takes place on an axis inclined to the right hand or to the left of the polarized chain itself. This idea seems to be confirmed by the latest researches of Prof. Hughes, who finds a + or − current produced in a wire around a magnetized bar according as torsion is applied to the bar in one or other direction. This should be remembered in studying the diagrams of polarized chains used in explaining the actions of currents and magnets. These are based upon correspondence to static charges, and are not offered as pictures of actual processes, but simply as aids to the imagination in forming ideas as to probable actions: it is evident that these actions are of the nature of motion in the case of currents and that motions cannot be thus pictured.

802. Whenever a magnetic body and an electric conductor are brought near to each other, or moved in each other's neighbourhood, they react upon each other if either one of them is under the influence of either force, magnetism or electricity. A magnet will produce a current in the conductor if either is moved under certain conditions; electricity in motion as current confers magnetism on a magnetic substance. The reason of this reaction is that the two are really different manifestations of the same force, and are due to different actions of molecules in a state of polarization; the electric action is that exerted in the line of polarization; magnetism is the action at right angles to the line of polarization; it is exerted in every direction at right angles, and, as a consequence, magnetism has in itself no directive power, and, strictly speaking, *no polarity*. The apparent polarity, like the directive power of magnets, is not the property of any single magnetic substance or object, but is the consequence of the mutual reaction of two or more such objects. It is the possession of magnetism by the earth, which therefore acts as one such body, that confers upon magnets their apparent directive power.

803. The source of all the mutual actions of magnets and currents is to be found in that property of the molecules of matter which we call *induction*, a power of acting externally upon other molecules. Within the electric circuit itself this power sets up the condition of "polarization," or arrangement of molecules in an order of regular sequence (+ −) (+ −) (+ −); but besides this action *in the circuit*, a similar action is exerted *around the circuit*, which tends to place surrounding molecules in a parallel polar order. But while the first action is consistent with a

transmission of energy along the circuit, and is thus of a dynamic character, involving a constant rotation of the molecules on their axes, the second is static, and changes only when there is a change of conditions. Thus, if we pass a current into a submarine cable, two conditions of polarization are set up; one in the line of the wire: the second in the surrounding matter, in the form of an *inductive* circuit from each successive point of the wire through the water to the other pole of the generator.

804. This latter absorption of energy is called "charge," and the current cannot be set up, that is, the *conductive* circuit cannot be completed, till from point to point of the wire the inductive circuit is completely charged, as explained § 95; this is the cause of what is called *retardation*, and hence the rate at which signals can be transmitted through a cable depends upon the nature of the inductive circuit it forms, or its "inductive capacity." But once this charge is given, the inductive circuit retains it, and absorbs no more energy from the current (except what is lost by *leakage*); current can be sustained upon the ordinary laws so long as no change is made. But when the current stops, the energy of charge flows out of the cable as a current, and no current can be sent through the cable, in the opposite direction to the first, until this first charge is passed off and a new one of the opposite order is set up.

805. Now magnetism is of the same order as charge; it is a static condition of the molecules, set up by energy absorbed from an electric current (or other source); while this condition is being assumed the process acts as a resistance and a retardation; but once it is set up, it is static, requires no more energy, and the energy will be retained, or given up as an electric current, according to the nature of the body in which it is produced.

806. To apprehend the consequences we should regard the electric circuit as a simple chain of polar molecules and individualize the molecules, which I shall do by drawing them as ellipses, of which the dark part will represent the + end, or the direction in which we may conceive the supposed electric current to be travelling; the white, or − end, being that connected to the positive pole of the battery. Fig. 79 is a section of such a chain, looked at from the positive pole, that is to say, the − end facing the observer, with the line of electric polarization passing through the centre.

The molecule exerts that action which we call magnetism, at right angles to the polar line in every direction, as represented by the arrows; but this action has no *directive* power, no *attractive* power; these depend upon external conditions.

FIG. 79.

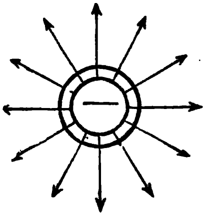
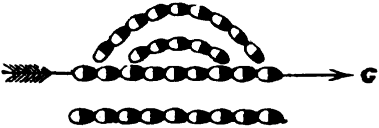


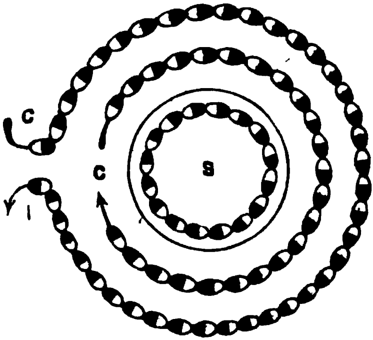
FIG. 80.



807. But the molecule, or, more correctly, the polarized chain, has the power of ranging all surrounding molecules in similar order, as shown in Fig. 80. The upper lines are intended to convey the idea of the inductive circuit set up as "charge." The lower parallel line represents the magnetic conditions to be further developed.

808. If we conceive the polarized chain C, of Fig. 80, to be formed into a circle, as in Fig. 81, we obtain the two effects in

FIG. 81.



different ways. Let S be a section of a bar of steel; its molecules arrange themselves in the form of closed chains, and as steel possesses the power of retaining this condition, it becomes a magnet; the forces exerted at right angles to the direction of polarization, all combining and acting in the line of the bar, as shown in the upper bar S N, Fig. 84, and also in Figs. 82 and 83. The difference between the two extreme faces of this bar is that, looked at from the exterior, the lines of polarization turn to the right in S and to the left in N, as seen in the two polar faces shown in Fig. 84. There is no difference of property, no inherent directive tendency in these ends; but in England we call the face S the south pole of the magnet because it ranges itself in the earth's magnetic field, facing to the south pole of the earth. In France they call it the N., or Boreal pole, because the north pole of the earth has, in fact, the characters of what we call the S pole of a bar magnet, § 749.

809. But action takes place externally, as well as within the ring. If I C, Fig. 81, is regarded as a ring of wire, its molecules, of necessity, swing into the polar order, and in doing so constitute a galvanic circuit, which will complete itself as usual; in consequence, a momentary current is generated or induced in this "secondary" wire as soon as current passes in C: but only one wave of action is produced, no current continues to flow in I C. As soon as the primary current ceases, all the molecules resume their normal position, and in the act of doing so a current is again set up in I C, but in the opposite direction to the first. If S is iron, instead of steel, it loses its magnetism, and the energy it had stored up is employed in increasing the energy of the current in I C, and also in producing an *extra* current in C itself, continued after the battery is cut off. These all react upon each other in such manner that these currents are not, as usually considered, single currents, but consist of several pulsations of maximum and minimum force analogous to the swings of a pendulum raised and let fall. The current in the outer, or secondary wire, is in the reverse direction to that of C itself when the contact is made: at breaking circuit the induced current is in the same direction as that of C. As these currents are each the result of single and equal swings of the molecules, their "quantity" is the same, for quantity is simply a function of the molecular actions. But the E M F of the breaking current is much the greatest. The reason is obvious: in the first, energy is being taken up rather in the core S than in the wire I C: in the last, that energy is given up to I C and added to its own charge.

810. If S, instead of being a bar of iron or a bundle of iron wires, is made of an insulated iron wire wound up in a helix similar to the other wires, it will still act as a magnet, though less forcibly, owing to the breaks in the longitudinal or magnetic lines, but the *extra* current will then be formed within itself and the wire will give off sparks.

811. The *direction* of these and all the other actions among currents and magnets, *induced* by motion (which includes the

setting up or cessation of a current, these being equivalent to a motion of approach or withdrawal), is governed by a general law first formulated by Lenz. *The direction of the current set up by any motion will be such as will resist that motion, and vice versâ.* Now currents having the *same* direction, that is, parallel, *attract* each other; therefore a current in the *opposite* direction, which *repels,* is set up. The order of the lines of circular polarization in magnets (Fig. 81) acts in the same manner as would the corresponding current, which is represented by C. We may see in this some analogy to the action of two wheels in contact; when one is rotated in one direction, it sets up, in the other, a motion in the opposite direction. Therefore the induced current at "make" is in the opposite direction in the wires to that of the primary, as then the two currents *repel* each other: at "break," the induced current is in the same direction as the original or primary current, as this resists the demagnetization or withdrawal of the magnetic energy, or magnet.

812. In consequence of these various relations, a wire wound spirally round a bar of iron magnetizes it in a direction determined by the direction in which the wire is wound. On the other hand, if the bar be magnetized by any external means, as by bringing another magnet in contact or neighbourhood, a current will be induced in the wire, and the direction will depend upon that of the magnetism set up, and also upon the direction in which the wire is wound. Helices are called *dextrorsal* or *right-handed*, when, looking at them from the end at which the current enters, or at which the coiling of the wire commences, the wire turns from left to right over the core as the hands of a watch. Fig. 82 is a right-handed helix, and, as it shows, such helices give South polarity to the end at which the current enters. In *sinistrorsal* or *left-handed* helices the

FIG. 82.

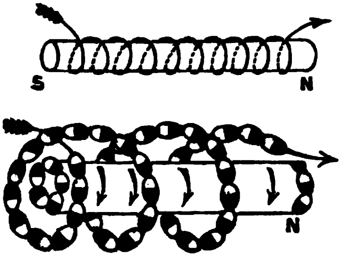
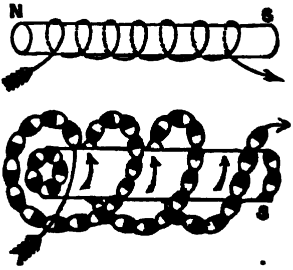


FIG. 83.

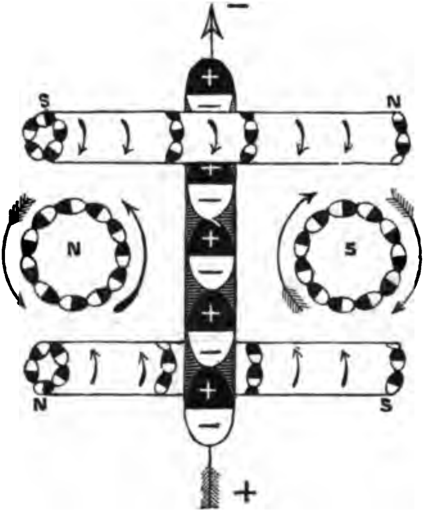


wire, under like conditions, turns from right to left over the core, as in Fig. 83, and gives North polarity to the end at which the current enters. A right-handed helix becomes left-handed if looked at from the other end; therefore when the wire of a right-handed helix returns over itself, by continuing to wind in the same direction, the upper layer becomes a left-handed helix; but as at the same time the direction of the current reverses as regards the core, the mutual reaction of wire and core is the same in all parts.

The figures speak for themselves, and show the mutual molecular relations as well as those of electric and magnetic polarity, the effects produced, and the reason of them.

813. Fig. 84 carries these relations a stage farther. The electric conductor is shown as a line of molecules upon the arrow which marks the direction of the current; four magnetic bars surround it, above, below, and on each side, and the molecular arrangement of these shows at once why they place themselves as they do (assuming the earth's influence to be neutralized): the ends of the two side magnets correspond with those in Figs. 82 and 83, as the other two magnets do with the

FIG. 84.

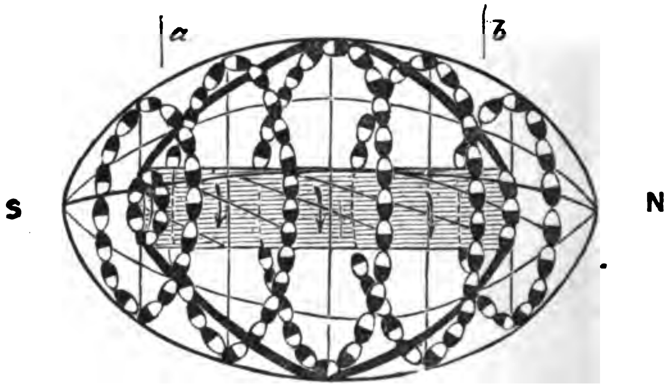


bars in those figures. It will be seen that the magnets arrange themselves as though the lines of polarization were actually currents all made parallel with the current itself, and just as the corresponding helices would if currents were traversing them.

814. We have now to consider how the magnets react. A magnet is not merely a bar of metal; it is linked to the surrounding matter in which are completed the lines of magnetic force, and which constitutes what is called a *magnetic field*. which field is an integral part of the magnet, whether formed in surrounding matter, or concentrated in a mass of iron connecting its poles. When a magnetic substance is near, it draws these lines towards itself, and by entering them becomes magnetized, but in ordinary conditions we may regard the lines of force as inclosing an elliptic space round the magnet, as shown Fig. 38, p. 100, and explained §§ 119-120.

Fig. 85 gives the idea more completely. From it we can see that the lines of force of the field, which inclose the ellipse,

FIG. 85.

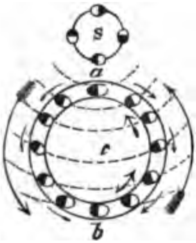


may be looked at from a twofold aspect. They are commonly treated as set up by the *poles* of the magnet, and as completing the circuits of *magnetic* polarity; for many purposes it is desirable to so regard them, and this view is presented by the elliptic lines, which correspond to the arrows of Fig. 38. But we may with equal truth consider that the polarized condition is set up by the circular polarization of the magnet forming the *vertical* circles, and so regard the elliptic or magnetic lines as being set up indirectly by the action at right angles of these circles; both actions no doubt unite as real causes of the magnetic field. We shall thus understand why the *inductive* power of a magnet is so much greater at its middle, while its *attractive* power is so much greater at its ends. The attraction is a function of the general law that parallel currents attract each other; there is, in fact, in all spiral conductors a tendency to close up, because of this attraction between all the partial currents. Now, if we conceive another figure like Fig. 85 brought near it endwise, it is evident that to make the lines of polarization alike, the north end of one must be presented to the south end of the other, and that then not only do the circles of the bars agree, while all the circles of each magnet, internal and external, attract each other, but the projecting lines of force of each magnet become incorporated with those of the other, and the result is a new elliptic field, as shown Fig. 39, p. 110. Hence, naturally, long magnets have the greatest attractive power, for they may be regarded as such combinations of smaller ones, combining their magnetic force, just as the union of galvanic batteries in series combines their electromotive forces. But as to induction, it is evident that the external circles are affected by those of the bar more powerfully at the middle than those at the ends can be by the whole length of the magnet, as this influence obeys the law of the squares of the distance; therefore, speaking roughly for illustration's sake, if we consider the inductive action of each circle of the bar to be equal, and call it 10, a circle at the middle will have a force of 20 exerted upon it by the two end circles, but a circle at the one end will be acted upon by the middle, 10, and the other end, whose distance is doubled, will give only $10 \div 2^2$ or 2·5, a total of 12·5 upon an end circle against 20 on the middle circle. This is the reason why a coil of wire with a current passing through it will draw a magnet into its middle, or *vice versâ*, the arrangement according with that shown in Figs. 82 and 83, while a magnet with the opposite arrangement placed within a coil will be forced out, because the two fields would be incompatible.

815. If we examine the actions which will take place upon the molecules of a conductor revolving in any position among the lines of force of a magnetic field, as shown in Fig. 85, we shall see that different effects may be anticipated according to the direction of the motion; we shall be aided in examining the effects if we regard Fig. 81 as a vertical cross section of Fig. 85. If the axis of motion be in the central line, N S, and the motion takes place in the circles of Fig. 81, the molecules suffer no

change of position as regards either their relation to S or to their arrangement in the moving wire; hence no effect can result. If the axis be lowered, so that the motion takes place below the central line, it will be seen that each molecule, in order to retain its relation to the magnetic field, must in each semi-revolution swing half-way on its axis, in relation to its accompanying molecules in the wire itself. This is evident in Fig. 86, which represents such a ring of wire rotating on the centre *c*, in the direction of the outer arrows, below the magnet S, of which the dotted circles are the lines of induction. It is obvious that the molecules forming the wire, in order to keep their relation to these circles, turn on their axes in the direction of the small arrows, and in doing so set up a current in the wire, if a current really involves a molecular rotation. This *explanation* is, of course, hypothetical, but it is *a fact* that the motion of the conductor under these conditions does produce some action within the wire which results in an electric impulse.

FIG. 86.



816. This Fig. 86 is a very simple looking thing, but it is commended to the student as one of the very highest importance and involving the most essential principles of dynamo machines. Following Faraday, all writers speak very fully about "cutting lines of force"; they rest in that phrase, and no one thinks it necessary to give any reason *why cutting lines of force should generate a current* in the wire. This figure gives us the reason: the mere lines of force are nothing, *it is the rotation of the molecules of the wire while arranging themselves as parts of these lines of force that causes the current.*

Fig. 86 may be regarded as a Gramme ring, and some important ideas derived from the examination; it will be seen that the small arrows show a reversal of rotation on the axial line, so that if contacts were made at *a* and *b* we ought to get a current from the two halves, uniting as in the Gramme ring. But this neutral line is shown here as forming at the polar axis, while in the Gramme ring it forms at right angles. This is a necessary result of the circumstance that, as the Gramme ring rotates between the two poles, the lines of the magnetic field cross from pole to pole, and instead of being concentric circles round one pole, are formed at right angles to those circles. It would appear therefore that what we have to consider, is not the *cutting of lines of force* on one theory, nor the passage of the conductor from *a region of few lines to one of many*, or *vice versâ*, according to another theory, but the *angular relation at different periods of the rotation, between the line of the conductor and the lines of force of the field.*

817. If a plate of metal is revolved under or above a magnetic pole, or between the poles of a horseshoe magnet, but below the middle line of the poles, as new sets of molecules are brought into action, sets of opposing currents are set up in the conductor, and can be collected by means of a pair of springs, one pressing on the centre of rotation, at *c*, in Fig. 86, and the other on the circumference at the points where the currents meet, which in the latter case is on the radius between the poles of the magnet, or at *a*, Fig. 86. This was the first form in which Faraday demonstrated the setting up of an electric current by motion of a conductor within a magnetic field.

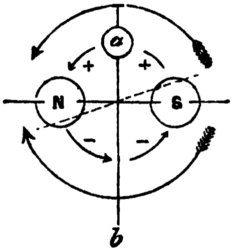
818. The currents so generated have two effects: 1, they heat the metal according to the regular law of current work, so that with a powerful current metals may be made red hot and even melted; 2, they offer a great resistance to the mechanical motion; of course this resistance can never rise to the extent of stopping the motion, because then no current can exist, and it is in no sense an obstruction offered by *the field itself* which arrests the motion, but purely that the force which causes the motion is exerted *within the conductor*, producing electrical motion among its molecules, instead of setting up an external motion *of the conductor* itself. This effect is strikingly exhibited if we allow a silver coin to drop between the poles of a powerful electro-magnet; its motion slackens as it enters the field, it may take even two minutes falling across the field, and will be found strongly heated. We have in this experiment the clear evidence of how mechanical energy is converted into electrical currents by dynamo machines.

819. If a bar of iron be surrounded with a helix of wire, a current of induction is set up when the iron is magnetized, and another in the opposite direction when it loses its magnetism; or the same effects are produced if a magnetized steel bar is inserted into and withdrawn from a helix. If a helix is wound upon the arms of a horseshoe permanent magnet, currents are in like manner set up whenever the armature is applied to or removed from the magnet; when a perfectly fitting armature of sufficient size is applied to a magnet the capacity of its metal for magnetism absorbs all the energy the magnet can exert into its own mass; the magnet then becomes inert as far as external influences are concerned; hence the application of the armature is tantamount to destroying the magnetism, so far as the exter-

nal relations are concerned, as stated § 144. In this action the energy of the external field is transferred to the armature, and if this has wire wound on it, which is therefore a part of the armature, and takes up part of the energy, a current is produced in this wire. The removal of the armature requires the application of external energy sufficient to restore the normal magnetic conditions, and then the energy in the armature passes into the form of current in its wire, just as in the case of induction coils. A little consideration will show that the action of dynamo machines is really a succession of such applications and removals of a solid armature.

820. All the practical forms of magneto-electric machines are based upon some of these principles. The earliest and simplest form consists of an armature of horseshoe shape revolved across the poles of a horseshoe magnet. The wire is so wound that if the horseshoe was straightened out, it would form one continuous helix, and in order to do this, it is usually wound on two similar reels, the inner ends taken to the commutator, and the outer ends connected together. When such an armature revolves over a magnet, the two ends are in opposite conditions, and therefore whatever action tends to develop a + condition at one end of the wire tends to develop a − condition at the other end, and both coincide in producing a current through the wire, as explained § 810. We may, therefore, examine the action upon one end of the wire in a complete revolution. Let *a*, Fig. 87, be the end of one helix resting on the neutral line *a b* of the magnetic poles N S, and the line of motion be from *a* to N. North magnetism is being gained; and let us assume that the relation of the helix is such that this renders the end +. As soon as *a* passes N its north magnetism is being lost, hence the wire reverses its polarity; as soon as *a* passes the neutral line it begins to gain south magnetism, and (as gaining north makes it +) this gives it − polarity, which on crossing S, and when the south magnetism is being lost, again becomes +. We have thus four electric impulses which, being however in couples, and not alternating, resolve themselves, as may be seen, into two electric conditions, which, it should be observed, correspond to the states set up in the wire ring of Fig. 86. By means of a commutator on the line N S, therefore, a current can be obtained in one direction, though not continuous, but composed of the action of four

FIG. 87.



distinct impulses, analogous to the varying electromotive forces set up by discharges of a condenser. The mode in which the commutator acts is explained § 864 and Fig. 100.

821. It must be understood that the point of change is not *practically* upon the line N S, but upon a line in advance of it, as shown by the dotted line, Fig. 87. The reason is that the various molecular changes, and especially the absorption of magnetism, require time; hence the line of actual break will take a position dependent upon the quality of the iron of the armature and upon the rate of rotation; it is even possible to conceive a rate of rotation such that no effect is produced at all, and in practice the motion cannot be advantageously increased beyond a certain rate, at which the maximum effect is produced.

A similar displacement of the neutral point occurs in all forms of dynamo machines, and the commutator brushes are made to move round the axis to some extent in order to admit of adjustment to suit the speed of rotation. See § 863.

822. DYNAMO-ELECTRIC MACHINES.—These modern generators of electric current have assumed so many forms that it would be impossible to enter at all fully upon their history, principles, or construction in the space at command. Therefore there will be little more attempted here than to give such information as may be of interest and use to the greater number of readers and refer those specially interested in this subject to works devoted to it. They are usually treated under two heads, as *magneto-electric* and *dynamo-electric*, the first of which depends upon permanent magnets, and the second upon electro-magnets excited by the current generated in the machine. But all are magnets and all are dynamic. All consist essentially of two systems

1. The *magnetic field*, which may be produced either by steel magnets or electro-magnets, but which it is desirable to make as powerful as possible.

2. The *armature*, which takes up the force of the field and converts it into electromotive force. Therefore while the term magneto may be conveniently used to classify machines with permanent magnetic fields, as a sub-section, the word dynamo includes all machines which employ mechanical energy to generate electric current.

823. HISTORY OF DYNAMO MACHINES.—Faraday obtained a current from a magnet in 1831; the next year Hippolyte Pixii of Paris produced the first machine for doing this practically: it consisted of an ordinary horseshoe magnet, under the poles of which a powerful steel horseshoe was rotated by a shaft; thus an electric impulse was produced in each half rotation in the opposite direction in the wire: the commutator devised to bring

these *alternating* currents into one direction, consisted of a spring attached to each end of the wire pressing upon a metal cylinder carried by, but insulated from the axis; these two cylinders were cut away as to half their circumference for half their length, so that when placed upon the axis they overlapped each other, and were separated by a small interval, thus forming a complete cylinder, except for these small gaps. Two other springs pressed on opposite sides of the axis, so that one of them was always in contact with one half cylinder, and as the axis revolved it touched alternately one or the other, and changed this contact just at the moment of change of direction of current in the wire; therefore each spring was always in contact with that end of the wire which was + or −, and being connected to the binding screws, delivered a current always in one direction.

It will be seen that this machine, rough and imperfect as was its construction mechanically, yet contained all the essential elements, and fulfilled the essential principles of the conversion of mechanical energy into dynamic electricity.

824. Saxton of Philadelphia reversed the construction of Pixii's machine in 1833, by fixing the permanent magnet and rotating the armature, which, while in no way altering the principles, simplified the action by putting the lesser weight in motion, and dispensing with two of the commutator springs, because the wires, moving with the axis, were connected direct to the cylinders instead of through springs.

Clarke of London, in 1834, still further modified the construction by fitting the permanent magnet in a box and causing the electro-magnet to rotate over the sides of the permanent magnet instead of across its poles. This is the instrument still well known in the shops as the "medical magneto-electric machine." Pixii's, Saxton's, and Clarke's machines are merely modified forms of one *type* or principle, and because the Clarke form is so well known I shall refer to this in future as "the Clarke type."

825. J. S. Woolrich produced the first practical machine for large currents and engine power in 1841; it was practically a compound Saxton machine with many magnets on a frame, and many electro-magnets rotated by an axis (thus greatly resembling the later Alliance machine), and it gave great pleasure to Faraday, who saw in it the rapid growth of the scientific infant he had presented to the world ten years before.

826. The next progress was made in 1856 by C. W. Siemens, by the device of his I core or armature, § 864, by which the loss of power in churning the air is minimized, as it enables a very

long magnetic core, with yet very short polar distance, to rotate in a very intense "field" with a velocity as great as the possibility of magnetizing will admit, and yet with no great circumferential velocity or mechanical momentum and stress. This I shall refer to as the "Siemens *core*" in order to distinguish it from the *armature* of his later machines, which constitute a different type.

827. H. Wilde made the next advance in 1867 in a very simple yet a very ingenious combination of two Siemens' machines. He used a common Siemens' machine with permanent magnets, but instead of using its current for work, he simply directed it into a second Siemens' machine with a large electro-magnet for its field, so as to obtain an intense magnetic field: the core which rotated in this therefore generated a much larger current, while of course requiring proportionate energy to drive it.

828. The next step, also a very simple one to our now extended knowledge, laid the foundation for all the later forms of machine. In the latter part of 1866 Mr. S. A. Varley, Professor Wheatstone, and Dr. Werner Siemens simultaneously carried the idea of *accumulation* a stage further than Wilde, who depended on the current derived from one permanent magnet to generate a stronger magnet. The new and fertile conception was, to commence with the very weakest magnetism, and make it generate the strongest, in fact to make *the electro-magnet magnetize itself*, by sending the current from the armature into the coils of the field magnet, each in turn reinforcing the other, till the maximum of magnetism was reached, starting from the small residual magnetism always present in iron once magnetized. The curious thing is that Mr. Varley had a pre-emptive right to this idea, because it was simply transferring to the new field, the very principle he had long before applied to his static electricity accumulator, § 50, yet it was years before his part in the matter was recognized, though he had actually patented the principle before either of the other co-discoverers who were credited with it had made public mention of the subject.

829. It should be mentioned here that glimpses of the idea of accumulation had been perceived by others; Millward of Birmingham in 1851 suggested the causing of the electro-magnets generated by the current to pass over permanent magnets so as to sustain their force. But Stephen Hjorth in 1855 clearly anticipated Wilde's combination of two distinct machines, by producing the same effect in one. A rotating ring of armatures, similar to that of the Alliance machine,

passed between the poles of a massive horseshoe magnet; the current thus generated was taken up by a commutator and passed into a pair of large electro-magnets, between the poles of which the ring of armatures also passed, and generated currents to be applied to work.

830. Mr. Ladd devised several convenient forms of machine for utilizing the principle of accumulation. He made large electro-magnets of boiler plate fitted with pole-pieces in which Siemens cores were rotated. In some he placed such pole-pieces at each end of two straight magnets with a core in each, one serving to maintain the magnetism as in Wilde's machine, and the other for the work. In others there was a polar system at one end of a horseshoe magnet, but the core consisted of two parts fixed at right angles to each other so as to come into action alternately, the two parts serving the same purpose as the separate cores of the other form. These machines were therefore identical with Siemens', but with the electro-field magnet instead of a permanent magnet.

831. The *Alliance* machine should also be mentioned in the order of development, though it introduced no new principles. It consisted of a ring or disc mounted on an axis and carrying near its circumference a number of straight or bar electro-magnets arranged parallel to the axis, which were carried by the disc between the two poles of stationary steel horseshoes arranged on a frame. and equal in number to the armature bars. A number of these discs were mounted on the axis with corresponding field systems around them constituting a compound Clarke type of machine very similar to that of Woolrich. The most important result of this machine, which was used for generating light, was the discovery that it was not necessary to *commutate* the currents for this purpose. The machine was a failure at first, because of the difficulty and loss at the commutator, but answered well when simple collecting cylinders and springs were used, and the alternating current sent to the arc lamps.

Holmes' machine, which was simply an Alliance, was patented in England in 1856, and in 1862 was used at the Dungeness Lighthouse, the first successful and permanent use of the electric light in England.

832. So far, all the machines were of the Clarke type, consisting of an armature of constantly reversed polarity, producing alternating currents, which had to be directed to the circuit through a commutator. In 1860 Dr. Pacinotti of Florence conceived the idea of a *continuous ring* rotating in the magnetic field, with the induced magnetic poles always

fixed in one spot, though the iron in which they existed was being constantly changed, and fresh coils of wire brought under their influence. It was really as a motor to be worked by a battery that the machine was devised, and the principle of accumulation which was destined to make it a good generator of current was unknown when in 1864 the invention was described in the *Nuovo Cimento* and several small machines made and deposited in the Florence Museum, which were to be seen in the Paris Exhibition of 1881.

833. Z. T. Gramme of Paris re-invented the Pacinotti plan as a generator in 1870, and his machine was used in electro-metallurgy. Von Hefner Altenech of the house of Siemens and Halske of Berlin modified the rotating armature in 1872. But here we enter on the modern period due to the excitement caused by the introduction of the Jablochkoff candle for electric lighting in Paris at the Exhibition of 1878. The numerous forms based on the Pacinotti ring need not be referred to, and a mere sketch of the historical development would be useless, so that at this point it is better to merge the description into an examination of the principles involved, and the mode in which they are applied in different machines.

834. EVOLUTION.—The doctrine or idea of evolution is now firmly grafted upon the scientific mind, and is extending itself into all the departments of knowledge. It teaches us that nothing is isolated, every fact, every idea holds some relation to others from which it grows, while it becomes a point of origin for others, sometimes continuing a direct line, sometimes constituting a point of differentiation, at which may originate several growths, proceeding onwards until there appears no relationship between their products. Such is the relationship among the various languages of mankind, as well as among the races of beings. Now, an important effect of this is that not only may the untrained mind be unable to see a connection between two apparently distinct things, but that there may actually exist *gaps in the line of evolution*, missing links in the chain, either lost, or which never had actual existence, except in the rudimentary condition.

835. In chemistry we have a number of "homologous series" and groups of series, which illustrate this very remarkably. Thus we have a series of radicals starting from methyl CH_3, and rising by the successive additions of CH_2 through a long line of substances, which gradually become denser; the addition of hydroxyl HO to any one of these substances converts it into a corresponding alcohol, such as the commonly known alcohol, the hydrate of ethyl, C_2H_5OH, and glycerine, not commonly

considered alcoholic in character, yet really so scientifically. Another atom of oxygen inserted in the molecule, in place of H_2, gives us the corresponding acid, such as the acetic acid of vinegar C_2H_3OOH, up to stearic, and the waxy acids and so on.

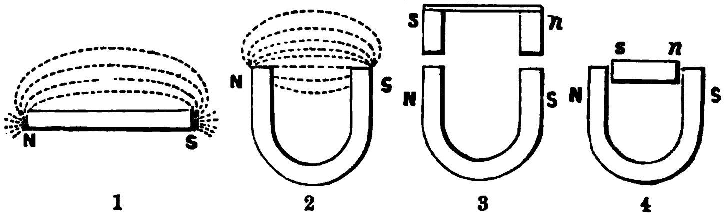
836. The same groups and substances may be classified upon other systems, such as that of types, but still with the same results which are now under consideration, the construction of connected lines and diverging groups, forming a clearly connected whole, in which, however, there are many gaps—substances which do not actually exist in nature, or have not been discovered, but the possibility of whose existence is evident, while some of them have actually been produced artificially in consequence of this foreseen potentiality of existence.

837. EVOLUTION OF THE DYNAMO.—It is such a relationship that I wish to present as existing among the different kinds of machines, not as a matter of fact, not as implying that the inventors of the different forms actually developed them in this manner knowingly, but as essential to the understanding of the resemblances and differences among the machines, and as enabling future workers to proceed upon definite principles, rather than upon rule-of-thumb processes, and costly tentative experiments.

In the endeavour to realize such a systematic conception, the first thing in development of correct ideas is to clearly distinguish between *things* and *appearances*, between fundamental principles and mere forms of construction.

838. To begin with, we should recognize that there is no real difference between a bar magnet and a horseshoe magnet,

FIG. 88.



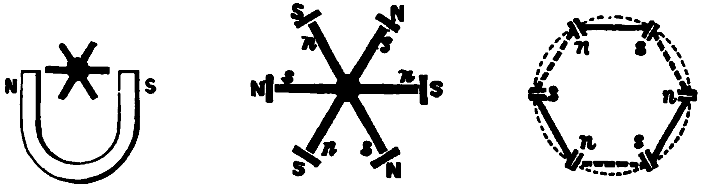
except in the form of the *field of force* set up between the poles, which adapts one form to some purposes and the other form to others. Thus it is evident that 2, in Fig. 88, is merely 1, with its two ends turned up by bending the middle, which allows the lines of force connecting N and S to be shortened, the resulting field to be reduced in area, and consequently increased proportionally in intensity.

It is less obviously, but equally true that an electro-magnet armature rotating over the poles of a magnet, as in Saxton's machine, or across the poles, as in Clarke's, acts precisely as does a straight bar electro-magnet passing between the poles, as in the Alliance and other machines: thus 3 and 4 differ in no way in type and action; nor do the Clarke and Alliance machines; the differences relate to mechanical construction, and to the most effective way of taking up the lines of force of the magnet. In all these forms the action is merely the placing of the iron of the armature in such position as will concentrate within its own mass as much as possible of the external field of the magnet and diminish its independent external actions.

839. It may be remarked here that each passage of the armature not only causes some molecular change in itself while taking up magnetism, but that it also causes a change in the molecular conditions of the magnet itself. If a wire is coiled upon a magnet, a current will be set up in it at each passage; in fact, many apparatus, such as fuse-exploders, are constructed upon this principle; the poles of the magnet themselves are wound with wire, and the current is produced by applying an armature and forcibly withdrawing it.

840. The changes of the magnetic field may be made evident by a telephone based upon a soft iron bar, which being applied to the magnet will be magnetized strongly when the armature is distant, and lose its force as the external lines concentrate in the approaching armature; at each such change a sound will be given forth. The efficiency of any armature may be tested by the reduction it produces in the external field, as shown by the diminished deflection upon a magnetic needle at a little distance.

FIG. 89.



1 2 3

841. *Compound Armatures.*—One stage of evolution from the mere bar is a radial armature, which Fig. 89, 1, shows is

merely a multiplication of the bars of Fig. 88, 4. The fact of its rotation in the plane of the poles N S, instead of across them, as in the disk form of armature, is a pure matter of construction, and this gives us one of the Lontin machines, which is built of a series of such radial systems, slightly overlapping each other, so that the field is transferred into one after another of the collection of bar electro-magnets which constitutes the complete armature system.

842. *Multiple Field.*—Another step combines the single ring of radial bars of Fig. 89, not with a single field magnet, but with an equal number of alternating field poles. We have then precisely the conditions of the Alliance type, different as the machines appear. If we look at 2, this is evident. It is of no consequence as to theory how the several poles N S of the field magnets are related; those at opposite points may complete the horseshoe, and then the two radii of the armature constitute a straight bar between its poles. Or we may consider adjoining poles N S as forming a separate field magnet; then the two adjoining radii form its armature (all being supposed to unite at the middle), and these, therefore, constitute a horseshoe electro-magnet.

843. *Apparent Ring Armatures.*—This leads to a new stage of evolution, which develops an apparently distinctive type, still depending on the same principles. We know (§ 838) that a straight bar and a horseshoe are the same in principle. We take, then, each adjoining pair of radii, acting as a horseshoe, but in no way differing in principle from the opposite radii, forming a bar armature to the *opposite* poles N S. We straighten this horseshoe so that it shall become a bar armature to the adjoinig poles N S, and thus we develop the three bars of Fig. 89, 3, and spaces, which we can fill up with three similar bars, shown in dotted lines. Curve the bars a little outwards as also shown in dotted lines, and we have what looks like a ring armature, but is so only mechanically. Electrically, it is a hexagon system of independent armatures, arranged in pairs so as to divide the forces of the field poles between them, and form a succession of consequent poles in the ring thus constituted.

844. This is, however, a very important stage of the evolution, for it is the basis of three machines wholly distinct from each other. (1) Fig. 89, 3, as rounded off, gives us the armature and the principle of the De Meritens magneto-electric machine. (2) in its preliminary hexagon form, 3 is the elemental ring of the Bürgin machine; which is often, but wrongly described as a compound Gramme machine. The fact that the Bürgin

armature is materially constructed of a continuous iron ring is a detail of manufacture (though it has also other results not belonging to the present topic). Theoretically each segment is an independent bar electro-magnet, fitting to, and polarized by the extremities of the field magnet poles. (3) Again, as a ring, and also as a continuous metal core, 3 gives us the Brush armature, which is really composed of independent electro-magnets, and in so far is different from the true continuous ring of the Gramme type; it does, however, approach a stage further towards it, by a continual interchange of sub-segments successively building up the actual bar, and by reverting to the bipolar field system.

845. *True Ring Armature.*—At the next stage of evolution we pass from the *apparent ring* of Fig. 90, 3, to the true ring of the Gramme or Pacinotti type. In all the preceding forms independent poles have been created and reversed completely, and the wire of each segment has its independent set of alternating impulses, set up in and collected from it. But the essence of the true ring is that while, structurally, the iron core rotates and the iron is continually changing its magnetic state, the *true core*, the receiver of the lines of force of the field magnet, is stationary. This armature is studied § 871, after the necessary examination of the general principles involved.

846. *Wires and Magnets.*—We must now trace out another line of evolution which appears to be distinct, and yet is of the same order. The action of wires crossing lines of force appears to be of a different nature from that of wires wound upon a bar of iron temporarily magnetized; but the currents produced in both cases are due to the absorption of external energy, and to the rearrangement of the molecules of the wire while adapting themselves to the lines of force which they momentarily occupy; the difference is that in one case the wires form part of the magnetized system itself, and in the other they temporarily form part of an independent system.

847. *No particle of matter is independent*, and this is a fact so very little dwelt upon that it is of great importance to all true thought that it should be thoroughly realized and firmly grasped by the mind. Nothing in existence exists for or by itself; every atom of matter is in the place, and under the conditions it occupies, as a result of the sum of the various forces which influence it. This is a fact most wonderfully evidenced by the infinitesimally instant changes which we have been enabled to trace out in many forms of matter, as resulting from the most rapid intermittence of light and heat.

Thus, in a wire, each molecule is constituted of two atoms, held together (probably through the agency of polar forces corresponding to those of magnetism, and commonly attributed to differential charges of + and − electricity) by the force called "chemical affinity" or attraction, which force is, as shown § 556, closely related to electromotive force. The mass of the wire is held together by similar forces of molecular attraction, crystallization, and cohesion. All these forces imply energy stored in the matter and they are modified from moment to moment by heat and other external forces.

The actual arrangement of the particles of the wire is the combined result of all the forces influencing them.—These particles are simply in a condition of equilibrium liable to instant change.

848. Such a change occurs the moment these particles enter a "field of force," the energy of which is charged upon them, and introduces new conditions of balance. The excess of force, the new stresses set up against the pre-existing internal forces, involve an expenditure of energy in effecting the necessary molecular changes, and we have the conditions described § 537; the potential energy of the lines of force in the field becomes kinetic in the wire, and this energy therefore develops E M F, and, in effecting motion among the molecules of the wire, generates an electric current, according to the arrangement of those molecules—the number of conducting chains which they can constitute.

Therefore, in order to generate a current, the wire must traverse a field in such a manner as to continually change the arrangement of its molecules among themselves, and their relation to the sum of the actions exerted upon them; mere motion in a field may produce no effect whatever.

849. When a pole of a bar magnet is inserted into a ring of wire carrying a current, a reaction occurs between the two fields which, if concordant, tends to unite them into one, and as a consequence to place the two centres of the fields together; if discordant, that is if the lines of force are not in the same direction, a sort of conflict occurs for the possession of the space and matter in which the lines of force exist. In the first case we have *attraction*, and the ring of wire moves to the central plane of the magnet, in the other we have what is called repulsion. The current in the wire is also either increased or diminished during the action.

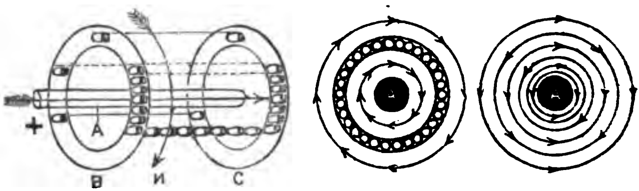
850. When a bar magnet is inserted into a ring of wire, not occupied by a current, it sets up a momentary current therein, opposite in direction *to the proper magnetizing current of the bar;* a mechanical resistance to the pressure is experienced, and the ring is for the moment repelled: these actions are examples of

Lenz's law, § 811. But it is not enough to quote a law, we should realize what is the cause and the process: the wire becomes a part of the *external* field and lines of the magnet, and has to arrange its molecules accordingly, as shown Fig. 38, p. 100, while a magnetizing current is part of the *internal* lines, an integral part of the magnet, and its molecules are ranged to correspond, as in Figs. 82, 83.

851. In order to make these mutual reactions intelligible, it may be well to develop a little the considerations presented §§ 806–14. In Fig. 79 we have a section of a current, showing radial lines of force, upon which magnets place themselves tangentially; those radial lines may perhaps be regarded as sections of the lines of static electric induction, springing from all parts of the circuit towards all other parts, and resolving themselves into a sheath of lines of force, of static stress, parallel to the conductor. Magnetism and electricity are related to each other, their planes or lines of polar order and force being at right angles to each other, § 115. We may, therefore, expect some magnetic force to exist at right angles to the lines of conduction, and such exists in the form of rings surrounding the conductor. Not only do magnetic needles place themselves in the order of these rings, as already explained, but the rings themselves may be made visible. If we pass a current-carrying wire through a card on which iron filings are sprinkled, and tap the card lightly, the filings arrange themselves around the wire, thinning away as distance increases; they are, in fact, temporarily magnetised and unite lengthwise to form closed rings around the wire in the lines of equal magnetic force. It should be clearly understood that these rings have no polar actions or attractions; they resemble a closed steel ring which may be strongly magnetized yet have no apparent magnetism, because it is a completely closed field; at every section there is an equal N and S pole existing and combining together. It is true that a piece of iron, such as a filing, enters the ring and does then possess two poles, because its *capacity* is greater than that of the air; but these poles are purely *within the ring*, they exert no external actions because the iron is not an independent magnet, but only a part of the external lines of the wire and therefore its poles are related only to the wire. Fig. 90 is intended to convey this idea of a conductor: 1 is a perspective view, A being the conductor, and the arrow shows the direction of the current. B and C are two rings of magnetic force consisting of molecules polarized under longitudinal forces, shown by the dotted lines connecting the circles B C, these lines representing the stress due to differ-

ence of potential set up in the polarized chains constituted by static electric induction of which one chain is shown connecting the rings. Fig. 34, p. 95, represents one of the molecules in such chains lengthwise, while the horizontal arrows show its magnetic lines. The other parts of Fig. 90 are sectional views

Fig. 90.

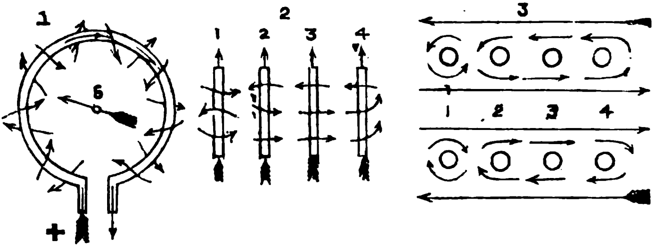


1 2 3

showing a ring B, C, of which 2 shows the molecular construction, and 3 conveys simply the idea of the lines of magnetic constitution.

852. A closed magnetic ring when cut across manifests true poles at which the forces are concentrated, and a similar effect can be produced on the circular lines of force around the conductor. This happens, in fact, when a wire is wound into a helix, forming a series of wires side by side, as is shown in Fig. 91: it should be remembered that this is no mere fancy; the iron filings prove its truth if we pass several wires side by side through a card as before. Fig. 91, 1, shows the conditions of a single ring of wire, the unit turn of a helix—in fact it is the

Fig. 91.

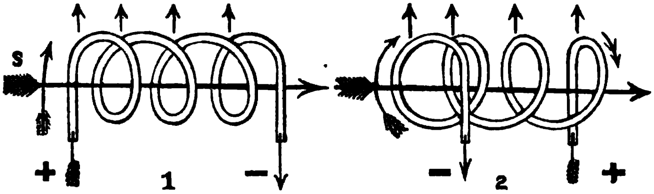


conductor A of Fig. 90 turned into a ring so as to bring all its lower side into the inner part; then it is evident that all its rings of force tend in the one direction internally, and in the opposite direction externally: the internal arrows show the resultant magnetic action, as though these rings of force constituted an internal vortex.

853. A series of such rings, placed side by side, is shown in Fig. 91 in vertical section at 2, which represents the further or left-hand side of the rings as looked at across the interior. It should be noted that the change in direction of the small arrows from those of Fig. 90 is the result of looking at them from opposite sides, and is evident in all three portions of this figure. In 3, which is a horizontal section of the helix, we see that the circular lines of force of the adjoining wires conflict as they enter each other, and are therefore broken up into their internal and external halves, which then unite to form lines of force along the whole of the wires.

854. Fig. 92 shows how different ways of winding wires bring these principles into action, and it should be compared with Figs. 82 and 83, p. 466, which deal with the same subject in a different manner. 1 is a right-handed helix in which the current gives S magnetism inside it, in accordance with the following law: *A current moving as the hands of a watch gives south polarity on the side from which it is looked at*, and vice versâ. It also gives N polarity on its outside. A left-handed helix is shown at 2 with the current reversed in direction so as to give the same polarity as 1, and it therefore really represents the wire of 1 continued to be wound, outside the first layer, in the return direction. In this way it is evident that the current is really running *in the same direction in all the wires which run in the same direction*, so that all the inductive actions are united.

FIG. 92.

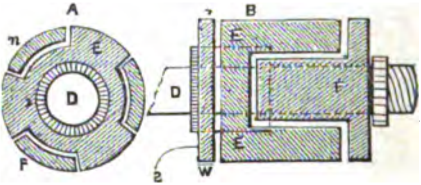


855. These helices also show how such a reverse winding upon compound armatures of any of the forms of Fig. 89, brings all the alternately reversed actions of each segment into a current of one direction throughout, so that only one pair of commutator springs is needed to collect the alternate currents into one: but such a commutator would require as many

alternating strips as there are sections, in order to effect the change as each polar change of magnetism occurs. Such a commutator resembles that of the Pixii machine, § 824, being composed of a pair of cylinders with alternate spaces cut away so as to constitute a crown wheel with a tooth for each magnet pole, so spaced that the two can interlap; one end of the wire is then connected to one cylinder, and a pair of springs takes up the current from each in turn.

Such a commutator is used upon the Weston machine for electro-metallurgy, consisting of a solid casting with three teeth slipped upon an insulating tube carried on the projecting axis, so that a similar casting slips on between its teeth without touching, an insulating ring fixing the distance to which the teeth enter each other so as to form a spaced cylinder upon which the two insulated collecting brushes press. The Weston commutator is shown Fig. 93, in cross section at A and longitudinal at B. D is the axis to which one end of the wires is connected, the other end being connected to W a brass ring firmly fixed on the axis but insulated from it as shown: E is one of the cylinders which presses up to and makes contact with W; F is the other cylinder which makes contact with the axis, and brushes in contact with one or another cylinder in turn take up the current.

Fig. 93.

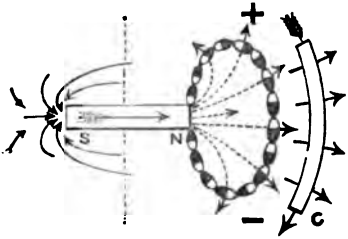


856. In § 851 and Fig. 90 it is shown that as a consequence of linear electric stress there are formed rings of magnetic order at right angles: then we must expect from the normal relations of electricity and magnetism that lines of magnetic stress, such as are formed in the magnetic field, should be attended with rings of electric polarization forming sections of the field: this is the effect shown in Fig. 38, p. 100, and in Fig. 85, p. 468; a consequence of this is that if we consider the electric stress as being the active cause and resulting in the differential arrangement of the + and − ends of molecules, the electric rings must consist of molecules end to end, while the magnetic rings consist

of molecules side by side, with the electric lines passing through them. It is desirable to clearly realize this now in order to trace the action which occurs in a wire when it enters a magnetic field.

857. Fig. 94 represents a bar magnet N S with one of the rings of electrostatic order formed on the lines of force issuing from its north pole. C is a conductor carrying a current, such as the ring of Fig. 91, 1, and shows how its magnetic lines agree with those of N S, the result of which is to draw the wire to the middle line of the magnet where the sum of the agreements is greatest: in these conditions the current and magnet unite; the space within the wire becomes part of the magnet and the return lines of force would be deflected to the outside of the wire where they would also agree with its lines. But if there were no current in C a different set of conditions would come into play. The full field cannot be drawn so as to be intelligible, but a little consideration will show that the space is filled with such circles as that shown, of all diameters; therefore the wire, as it approaches the pole N, will be continually entering fresh circles, with their magnetic lines in different directions, so that its molecules will be solicited in constantly changing directions in order to accommodate themselves to these changing conditions.

FIG. 94.



858. In Figs. 95 and 96 we can see what happens when a wire crosses the lines of force of a magnet. In Fig. 95 we have a vertical section of the field of a N and S pole as between the poles of a horseshoe, or those of a dynamo machine, showing the *lines* of magnetic force and the resulting electric *rings*; Fig. 96 is a section of the same field, in which we can see what occurs in a wire traversing it in the direction of the arrows: as it occupies the several vertical dotted lines, it cuts circle after circle, in each of which there is different angular relation to

the wire, which would result in a rotation of the molecules in a spiral line around the wire; here we have the explanation of what occurs in ring armatures of the Gramme and Siemens types.

FIG. 95.

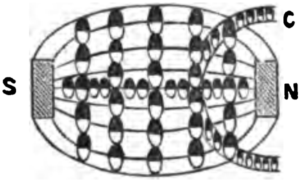
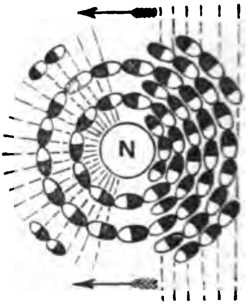


FIG. 96.



859. Such a field between two poles may be regarded as a bar magnet, without return or external lines. Therefore when a helix occupies the field its wires correspond to the several circles shown, and the molecules must form a continuous chain corresponding to these circles, and in taking up that position a similar spiral rotation is necessary.

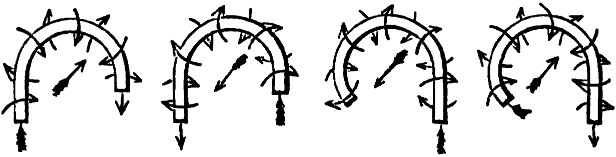
If the helix contains an iron core it concentrates the lines of force more speedily and more completely, so that Fig. 95 shows us what occurs in armatures of the types of Fig. 89.

Also if we consider the action of a ring descending vertically upon N we have a modification of § 856 and a more full idea of the actions on the wire: this action is shown at C as again a spiral rotation of the molecules, resulting from their relations to the different circles into which the different parts of the wire enter.

860 CURRENT AS A SPIRAL MOLECULAR ROTATION.—The actions thus presented indicate that electric current is not propagated in a direct line along the conductor, but in a spiral winding round the conductor corkscrew fashion. Such a spiral progress of apparent linear motion is found in other cases: in a vibrating metal rod giving out a musical note, a loose ring of paper comes to rest on the nodal points of the vibrations, and these form a spiral line around the bar; the phenomena of polarized light indicate that the undulations take place in all planes, which corresponds to a spiral propagation, just as a corkscrew looked at

edgeways appears as an undulatory line and is really such an undulation in all planes. Professor Hughes's latest examinations of the phenomena of magnetism demonstrate the existence of this spiral molecular arrangement, rather than a direct linear polar order of the molecules. The subject is not ripe for any very definite opinions, but I offer Fig. 97 as very suggestive. Assuming that a "positive" current implies a right-handed rotation in the wire, we have an obvious cause for the direction of the magnetic circles corresponding to it: for this purpose it is of no moment which may be the actual direction corresponding to the + current, because our making the point of the arrow correspond to N magnetism is purely arbitrary.

FIG. 97.



By reference to Fig. 92 it will be seen that 97, 1 and 2, are the front turns of a right-handed helix with the current in the two directions, while 3 and 4 are the same for a left-handed helix. 1 and 4 also show why a right-handed helix is the same thing as a left-handed helix at the other end, with current reversed, and therefore the same magnetic actions: 2 and 3 show the same, as they are exactly alike except that the beginning, or longer end, is exchanged.

861. **THE FIELD MAGNETS.**—There is little difference in this part of the dynamo machines; the earlier forms consist of mere horseshoe magnets variously fitted to act on the various types of armature: in the later machines the same horseshoe is really produced but usually in the form of two opposed horseshoes forming consequent poles in a complete metallic circuit: projecting pole-pieces are added to carry the poles around so much of the ring as is necessary, the extent of these projections depending upon the nature of the armature. There are two plans in use, which look different, yet are the same in principle. Fig. 98 shows the two opposed horseshoes let into common pole-pieces with projecting horns N S forming the circular field in which the armature rotates. This is the general type of the Gramme field magnets.

Fig. 99 shows the pole-piece and one arm of each horseshoe formed in one mass of metal, two such bars being secured to the cross arms to complete the system. This is the type of the Siemens field magnets, in which the arms are made of a number of parallel bars of wrought-iron curved to the required shape. The same type is employed in the Bürgin, the Maxim, and Weston machines, but solid castings are used.

FIG. 98.

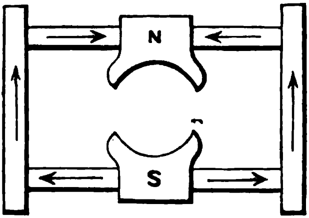
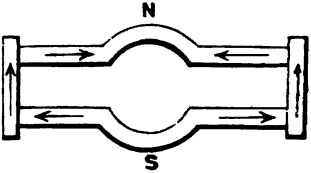


FIG. 99.



A comparison with Fig. 101 will show that these forms are in no way different in principle from the simple horseshoe magnet; the different field magnets are only different modes of concentrating a powerful field upon the armature. In the later modifications of the ring machines, instead of a single field between a pair of N and S poles, two, three, or more pairs are employed, and the ring is really divided into as many segments, in each of which the same action occurs as in the ring.

862. ACTION OF FIELD MAGNETS.—As one of the principal elements of the E M F of machines is the "intensity of the field," different systems of supplying the field magnets are employed. In the original machines, with permanent magnets, this element is comparatively fixed, and therefore the E M F generated is wholly dependent upon its other element, the angular velocity of the armature; as a consequence in any given machine of this type the *E M F is proportional to the speed of rotation.* The same law applies to electro-magnets fed by an independent source, such as a separate machine, or a distinct armature. This last plan is not quite so regular as the others; because the field magnet is itself modified by the reactions of the armature, as also are its several relations to two or more armatures. Even with permanent magnets a disturbing action occurs: poles are induced in the armature by the field magnets; in some forms, polarities are also induced by the current in the armatures, and this *current* will vary in the same field and at same speed, according to variations of the external resistance, and this will result in a varied reaction upon the field poles.

The conditions of the field are controlled by different modes of winding and of distribution of the feeding current as explained § 891.

863. *Displacement of the Field Poles.*—The axis, or direction, of a magnetic field of force, is of course the straight line between the poles, and the central polar focus of such magnets as Figs. 98, 99 is obviously the middle of the iron; but this is no longer the case when a rotating armature is in the field. Two actions then occur, which distort the normal conditions. (1) The wires themselves, carrying currents, have affinities with the lines of force in the field, and act upon them just as a moving body does upon a liquid, so that the lines of force instead of lying in the normal position of the field, are drawn aside in the direction of rotation. (2) The iron of the armature does not attain full magnetism until it has passed the focus of the pole, because it takes time to magnetize, § 821. But the pole formed in the armature attracts the field pole, and as the polar position is not fixed in a mass of iron, § 134, the field pole itself follows the armature pole, and the polar line of the field magnets is no longer symmetrical, and at right angles to the line of the magnet, but is drawn forward in the direction of rotation of the armature, as shown Fig. 87, p. 472.

As a consequence, the neutral points of the armature itself are no longer on a central line, but are moved forward in the direction of the rotation to an extent variable with the currents passing, and altering external resistances. This neutral point is that at which no E M F is set up in the wire occupying it, and therefore it is the position at which the collecting brushes must be set. If the brushes are on either side of the neutral point, the local E M F sets up currents resulting in sparks at the brushes; a certain amount of "lead" has therefore to be given to the brushes, and a power of adjustment, by moving on an axis, to compensate for changes in the neutral line.

864. SIEMENS' CORE.—This, which is mentioned § 826, is shown Figs. 100, 101: A is a solid soft-iron mass, of a section resembling that of an H girder, with the faces turned down to arcs of a circle. The wire is wound longitudinally, as shown in section in the middle of Fig. 101. The coil may be covered with a sheathing of wood so as to form a solid smooth cylinder, with grooves in the face to contain fastenings to hold the wood in its place. On the ends of the armature, brass plates are securely screwed to form the axis of rotation, and carrying at one end *p*, the driving pulley, and at the other end the *commutator*, *c*. This consists of a cylinder of ebonite fixed upon the axis, upon which are secured the two halves of a gun-metal cylinder, cut

diagonally, as shown; the ends of the wire of the armature are led through the end pieces and secured to these. Frequently, one of the connecting pieces is fixed to the axis, and one end of the wire to the armature instead of isolating both. Springs like *s*, fitted with a turned pad of steel or other metal, press upon the cylinder, and take up the current; they are usually made in one piece and cause great pressure and wear; it is better to cut them down as shown, in order to give more elasticity.

FIG. 100.

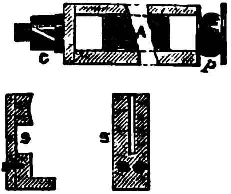
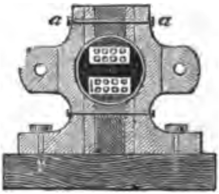


FIG. 101.



865. *The Siemens core* is used in a variety of *small motors:* Deprez's, Trouvé's, and Griscom's are pure Siemens machines sometimes with permanent field magnets, and sometimes with electro-magnets; in the Griscom, the field magnet is really the same as Fig. 99, but the extended arms are not used, but the magnet is made circular, leaving projecting poles at its opposite diameters, and the rest of the ring wound over with wire.

In these motors a slight change of form has been made which is considered or said to improve the action; either the field space is changed by allowing each pole-piece to partly overlap the circle, or the core itself is made slightly elliptic; in either way a gradual approach is made by the armature instead of its at once coming close up and maintaining a constant space between the faces of armature and field poles.

866. *Siemens'* and *Wilde's* machines, in which this core was used, consisted of field magnets the construction of which is shown Fig. 101: *a*, *a*, are two blocks of cast iron of such length as may be required in each case; they are separated by blocks of wood or other non-magnetic substance, and bolted together by brass or copper fastenings; a cylindrical opening is bored through, in which the armature, Fig. 100, rotates. At the proper intervals there are lugs, as shown, to which are to be bolted the actual magnets, either steel or soft iron, as required: *a*, *a*, form, in fact, the poles of a compound magnet, and may be

made in separate pieces for each magnet; all surfaces in contact with the true magnet being carefully faced so as to secure a large surface contact.

A comparison of Figs. 98 and 101 will show that the difference of these field systems is merely one of construction, but that their action is identical.

The arrangement of the machine itself is simply a matter of convenience of construction; in *Wilde's*, § 827, the large electromagnet is fixed on the foundation and the smaller permanent one mounted above it; each armature having its own driving pulley and strap. The construction of Ladd's forms is explained § 830.

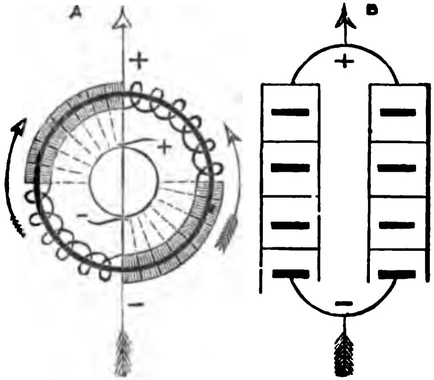
867. *The Gramme machine* was the first practical machine introduced with a *true ring armature*, § 845, the principal distinction of which is that it furnishes *a uniform and constant current in one direction*, while others give intermittent and alternating currents, which have to be arranged by the commutator. The reason of this is easily seen; in the earlier machines the wire in which the current is set up is constantly altering its position in the magnetic field, and is as *a whole* subjected to a growing and diminishing action in two opposite directions, hence the electromotive force set up is *of the nature of a succession of waves* alternately rising above and below the zero line: and the current resembles the stream set up by strokes of a pump. In the Gramme machine, although *each part* of the wire is constantly changing its relation to the acting magnetic field, *yet the wire, as a whole*, never changes its relation to, or position in the field; hence the inductive conditions set up are constant; the electromotive force set up is *of the nature of a constant fall of water*, and the current is a steady stream. To understand how this result is arrived at, it is necessary to examine the apparatus and the conditions from several distinct points of view.

868. *The Gramme armature* differs from those of the Clarke type shown in Figs. 88, 89 in being a closed ring of metal, instead of an iron bar forming the core of an electro-magnet induced by the field poles; yet it is really just such a bar, if we consider its true functions: it will be seen in § 871 that it is really two such bars dividing the field, and uniting their actions; the wire upon them being so arranged as to unite the currents developed. In order to effect this, the wire is not, as in ordinary electro-magnets, a length of wire having two ends forming a constant circuit; it is a continuous and endless piece of wire wound over every part of the ring. The current does not flow through this circuit in its entirety,

first one way and then the other, but two opposing currents flow in those parts of the wire which occupy, at each instant, a fixed relation to the inducing magnet, or rather no current flows at all (considering, that is, the circuit itself), but two equal and opposite electromotive forces are set up, which unite in producing current if an external conductor is provided.

869. The construction is explained by Fig. 102. The iron core is formed either of hoop iron, or preferably wire, wound up in a ring to prevent induction currents (commonly called Foucault currents in this sense). The conductor, the size of which is of course proportioned to the relative E M F and current desired to be obtained, is wound continuously over the core in one direction and its ends joined together; but though this wire is endless, it is necessary that there should be a constant connection with it at the points where it is cut by the vertical line + –. *Looking at the armature as a whole*, and as regards its relation to the magnetic field, the electromotive forces set up are shown by the arrows which, it will be seen, represent the same conditions as a pair of equal batteries connected with their forces opposed, as regards themselves, but in multiple arc as regards an external circuit. In such an external circuit, therefore, they combine to set up a current; if no external circuit is provided, no current is generated. But the *different parts of the armature*, as it revolves, are constantly changing their positions in the field, and therefore a temporary or shifting connection to the wire has to be made, as each of its turns crosses the vertical line. If the wire were a single layer, this could be accom-

FIG. 102.



plished by exposing its exterior surface and arranging a spring to touch at each point. Practically, this same condition is attained by dividing the wire into a great number of equal sections, and attaching a conductor to each section in such a way as to make it act as would the single turns of the wire itself. This is effected by bringing these conducting branches out to an insulated cylinder faced with as many insulated contact pieces as there are sections of wire to be connected; this is shown by the dotted lines in Fig. 102, which represent the connecting wires; springs pressing on the contact pieces make, practically, a constant connection with the two halves of the circuit on the vertical line. In the machine itself these springs are replaced by brushes of wire thick enough to press on, at least, two contact pieces. The object is to prevent any actual break of contact in order to avoid the production of sparks at the commutator; there is also less mechanical resistance than a strongly pressing spring would cause.

870. We have only to conceive this armature inserted in the place of the Siemens armature in Fig. 101 in order to follow out its relations to the magnetic field, and to trace out the points in which a ring armature differs from the bar or horseshoe types. In these latter the armature, *as a whole*, reverses its relation to the magnetic field, and *assumes two distinct conditions at different times*. In the ring type, *the different parts* of the armature assume these conditions *successively*, and thus set up a rotation of the molecules of the wire as in other cases; but *as a whole, the two distinct conditions are assumed at the same time* in the two halves of the armature on each side of the vertical line in Fig. 102.

In the revolution of an ordinary armature, the electromotive force set up in the wire, as a whole, varies with its distance from the inducing magnet, and, in consequence, the current produced is variable. Now, the various sections of the ring occupy all these different positions at once; the consequent variable electromotive forces are, therefore, generated in them as in the ordinary armatures; but these sections being connected together in series, they act exactly as do a series of cells of different electromotive forces, and the resulting electromotive force in each of the sides of the ring is constant, and is the sum of all those of the sections it contains. The action of the two halves of the ring A, Fig. 102, corresponds, therefore, in all respects with that of the two equal batteries, shown in B, as coupled in multiple arc. In both there are equal opposed forces resulting in static equilibrium, and in both there is combined action on an external circuit.

871. **Theory of the Gramme Ring.**—The foregoing accurately describes the resulting action, but the causes are to be found in the working of the principles, explained §§ 846–859, some co-operating, and some opposing.

Two of these actions may be traced in Fig. 103. N S are the field poles, not so far extended as is now usual in practice, and leaving out of consideration the distortion of the field explained § 863. If we consider the wire alone, we see that it is (1) a helix traversing the field and cutting its lines *upwards* from 5 to 2, and downwards from 2 to 5, therefore producing opposite currents in the two halves of its rotation. (2) That the helix (disregarding the edges which lie parallel with the lines of force) consists of two wires, on each side, cutting the lines, therefore there must be similar induction in each, generating an opposing E M F in each turn of the wire, somewhat stronger in the outer position than in the inner, because of its greater nearness to the pole. (3) If we now insert the iron core, it absorbs the lines of force into itself by its greater capacity, and these lines now exist *only in the spaces between the field poles and the ring itself:* the iron core becomes a shield to all the space within itself, and constitutes practically a magnet suspended between the two field poles. This results in two actions. (4) *The helix is now resolved into a single line of wires cutting the lines of force,* under the conditions of §§ 858–9. No opposing

Fig. 103.

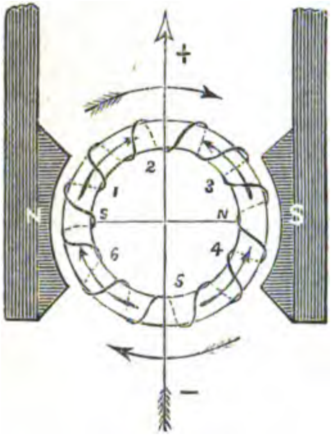
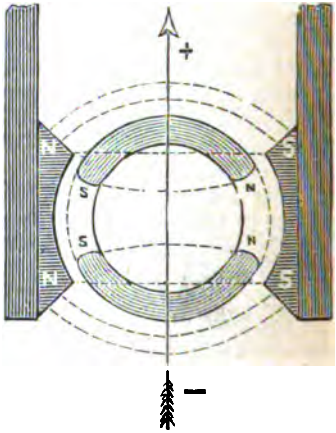


Fig. 104.



EMF is set up in the inner portion of its wires because these are no longer in a field of force at all, they are merely conductors connecting the outer wires—in fact we regard the core as a *fixed magnet* with poles opposed to the field poles and the helix as a wire passing between these poles. (5) But though the *magnet is fixed* in space, the iron in which it exists is being constantly changed; change of magnetic state means altered molecular arrangements, a consequent rotation of the molecules with the accompanying reaction upon its surroundings. This "polar introversion" is considered by Count Du Moncel to be the chief source of EMF in the Gramme. (6) This constant magnetic change in the iron has a disadvantageous result, because it heats the iron, and is doubly injurious, by the consequent waste of energy and by increasing the resistance of the wire by the heat thus given off, in addition to that due to the current in the wire.

872. An entirely different set of actions is illustrated by Fig. 104. Here we consider the core as constituting two bar magnets, fixed in space, and taking up the lines of the field; then the wire represents a succession of helices drawn along these bars, and we have the conditions of §§ 850 and 857. Starting from S, in the upper curved bar, each section is exposed to growing inductive action, till it reaches the middle line, where all the inductive actions of the principal magnets, and of the included bar, are at a maximum, and tend to make the wire led out to the commutator positive, or +; on passing the neutral axis the current is reversed in the wire. We may now consider the helix as traversing a bar extending between the two neutral points, with consequent N poles at the middle; in such a bar no reversal of current would occur, but one in the same direction would be generated all along the bar, with a reversal on entering the other semicircular bar on the neutral line at – : in this path there would also be the effect of "polar introversion" of § 871 (5).

873. We have, therefore, three distinct influences co-operating in the Gramme machine:—

(1) *The outer portion of the wire* cutting the lines of force between the field poles and the induced core poles, § 871 (3). As to this, the wire inside the core is inert and a mere resistance: on the edges a partial action is exerted because the lines of force are not all absorbed direct into the core, but are partly bent round towards it. Several of the modern machines are specially directed towards utilizing this inner wire, as by causing the pole-pieces to inclose the armature as much as possible.

(2) *The helix action* in traversing a bar magnet, § 872, which acts on the whole of the wire.

(3) *The polar introversions* of the core, § 872 (5), also acting on the whole wire, but most strongly on the outer portions, and accompanied with loss by the heat of demagnetization.

874. THE SIEMENS DRUM ARMATURE.—The object of this is to minimize the inert portion of the wire: the core is no longer a ring, but a mass of iron constituting the inner induced magnet and represented by a cylinder of sufficient thickness to take up the field. The wire is wound along the length and across the ends of the cylinder, so that it represents only the single wire cutting the field on each side in opposite directions, and therefore generating a current in one direction, reversed as it crosses the neutral line. Exactly the same actions occur as in the Gramme wire, § 873, and the difference is in the relative amount of idle wire in the two; the wire across the ends of the cylinder is inert in this case.

875. There are various ways of winding on the wire: that used in the Siemens machine crosses the cylinder diametrically at one end, but at the other it passes from the middle of one polar arc to the extremity of the other arc. The wire is divided into 8, 12, 16 parts according to the size of the machine, all united, by means of the commutator segments, into one endless wire, as in the Gramme, but differently arranged.

The winding of the wire is so arranged that the layer which is on each side facing the middle of the pole-piece corresponds to one turn around the cylinder. Let us conceive an armature of 8 such turns, therefore of 16 wires, of which the *ascending* turns 1, 3–15 shall be regarded as related to the N pole, and on the left hand (as in Fig. 103), and the descending turns 2, 4–16 as related to the S pole on the right. Let us begin with 1 at the middle of the N pole, and connected on the further end of the cylinder to the lower end of 16 which faces the middle of the S pole. The commutator consists of 8 strips which we may call *a*, *b*, – *h*, of which *a* lies nearest to wire 1: this upper end of wire 1 is now led across the end of the cylinder to the upper end of the S field pole, where it descends as wire 2: the winding has thus advanced one-eighth of the circumference, *against the hands of the watch;* the cross wire is also connected to armature segment *a*: that is to say, the *end of wire* 1, and *beginning of wire* 2, are joined together at *a*. Wire 2 then commencing at *a* and crossing the lower end to the point one-eighth further advanced—that is, to opposite the lower point of pole N, we may consider as wound round and round the cylinder between 2 and 3, so as to fill up one-eighth of the cylinder: the turns in the space corresponding to 2 and 3 therefore constitute one helix crossing the cylinder, and constituting the next collection of wires which will come into the highest action as the cylinder rotates in the direction of the hands of a watch. The end of 3 and the beginning of 4 are in like manner connected to segment *b* of the commutator, that is to say, to the next one to *a*, working round the commutator, as the wire itself does, against the hands of the watch.

876. *The neutral points* are, as in the Gramme, on the vertical section of the field, and the currents set up in the various sections of the ring are just like those in the Gramme as shown § 868 and Fig. 102. But little E M F is generated in the sections 4–5, 6–7, which occupy the middle of the field and whose ends are connected to the commutator segments near the neutral line: they only conduct the current to the neutral points. Therefore the commutator brushes *overlap at least two segments*, thereby short circuiting these idle portions of the wire, or cutting them out of action so as to reduce the resistance. A similar object is attained in like manner in the Gramme, and so long as the brushes occupy the neutral axis the only sparks produced will be due to the vibration and jumping away of parts of the brushes. If any considerable sparking occurs it proves that the brushes do not occupy the true neutral points due to the actions explained § 863. The Siemens field system is shown Fig. 99, p. 490.

877. The Siemens *drum* is a link of evolution between the *bar* armature of Fig. 101, and the Pacinotti *ring*. It is *not derived from the Gramme* machine, or a mere modification of the Gramme ring as it is commonly said to be. It is likely enough that it was suggested by the consideration of the Gramme action; but it is truly the Siemens core of Fig. 101 with its middle plate divided into two and brought out towards the ends of the pole-pieces: in fact it utilizes the action which occurs in the old core, direct upon the wires as they pass the field poles, but which is not utilized in the old machine because the magnetic action of § 872 is in it so much more important than that of the wire itself, § 871 (4), while these functions are reversed in importance in the modern ring form. None the less, the Siemens ring is really a compound of a number (in § 875 this number is 8) of the old Siemens ⌶ cores, in which the polar ends are extinguished while the connecting webs are divided in two, and expanded into the ring, in the same manner as (§ 843) we saw in Fig. 89 (2) the corresponding radial bars (which really represent these webs), converted into the ring of Fig. 89 (3).

878. The Brush Machine.—This is usually made to develop

a much higher E M F than is employed with other machines, but this is not a necessary consequence of its principles. It is commonly described as a derivation of the Gramme, but it is wholly different in principle, the sole resemblance being the continuous iron ring of the armature, in which the magnetism travels to some extent, though it is largely intermittent, as if built up of independent segments like the Meritens.

879. *The core* is a modified Pacinotti ring, having an intrinsic distinction from the Gramme ring: it has projecting pole-pieces between the sections of the wire which come close up to the field poles and therefore take up a very much higher magnetic charge.

The Pacinotti core may be regarded as a solid ring of the full size of the armature, in which have been channelled out spaces to receive the wire. The Brush core consists of this same ring built up out of two or more parallel discs insulated from each other, or of a ring so deeply channelled as to nearly divide it into discs; the outer halves carry the projecting pole-pieces, also deeply channelled: the object of these channels is to prevent the formation of induced Foucault currents in the mass of the core itself, because these transfer the inducing action from the wires, where it is wanted, to the iron where they would be not merely useless, but also injurious by generating heat. This forms eight spaces which really constitute independent bobbins.

880. *The wire* is wound in these spaces as usual, always in one direction, but not connected into one length as in the Gramme and others: the inner ends of each opposite segment are connected together; the outer ends are kept independent and connected together as required by the commutator, which here deserves the name, as it is not a mere collector. The effect is that the two opposite segments constitute a true Saxton electro-magnet in principle.

The action of the Brush armature, therefore, is almost wholly that of § 873 (2), the reaction of the core on its helix: there may be some of the effects of the polar introversions, but there are no effects due as in 873 (1) to the wires themselves cutting the lines of the field, because the opposite sides of the wire cut those lines from similar poles in the same direction.

881. *The field system* is a simple horseshoe electro-magnet across the polar ends of which the ring rotates, on precisely the same principles as in the Saxton machine, § 824. But instead of a single electro-magnet, there are two, a similar pair being arranged on the other side of the disc, with same poles opposed, so as to influence the ring on both sides, and therefore the

typical horseshoe of the Saxton is straightened out (theoretically) so that its polar ends are fully acted on by the inclosing field poles, which are so expanded as to act upon three of the segments at a time.

882. *The commutator* is built up on the axis of rotation, as in other machines: it consists of a metallic cylinder for each pair of armature segments (1 for each theoretical electro-magnet) of the system: this cylinder is divided into two insulated halves and the ends of the wires of the pair are united to these, as in the Saxton and other old machines. But at each joint of these semi-cylinders, which are adjusted on the axis at the same angular position as that of the segments they belong to, a space is cut away equal to one-eighth of the circumference and filled with an insulated piece of metal which corresponds to a segment which is cut out of the circuit when these spaces are under the collecting brushes and the corresponding segment is in the neutral space.

The brushes are mounted upon a rocking frame which allows them to be shifted around the axis to bring them into the neutral point. The actual break of circuit involved in this machine, as also its high E M F, result in heavier sparking than in the other machines. The brushes are divided into two pairs, each acting upon two of the cylinders, so that the brushes can be connected to act as one in multiple arc, or in series according to the actions required.

883. THE BÜRGIN MACHINE.—This is noticeable for its great simplicity of construction, and from the openness of its structure allowing free circulation of air, and so lowering the risks of heating. Its field system is that of Fig. 99, but made of cast iron so as to give great solidity, and allowing the pole-pieces to project a little so as to give partly the effect of Fig. 98. A gun-metal framework attached to each side of the field system carries the axis of the armature.

The armature consists of a series of hexagonal cores, like Fig. 89 (3), composed of iron wire wound into the shape. On this, the copper wire is wound so as to form a distinct electro-magnet of each segment of the rings, with its turns increasing towards the middle of the segment, in such way as to swell out the section of the armature to that of an irregular ring, exposing the angles of the bare iron, and allowing them to approach closely to the corners of the field poles, and be strongly magnetized. The ring thus formed is usually, but erroneously, described as a Gramme ring of only six sections; its action is entirely different from that of the Gramme, for it consists of the making the two segments which cross the ends of the field poles into pure bar electro-magnets, just as in the Clarke type. It is here only that the real action occurs, and the intermediate sections which lie in the hollow of each field pole, contribute little to the development of E M F.

A number of such rings are fixed on the axis with their corners slightly overlapping each other, in such way as to concentrate the action of the field upon each of them successively: six, and even ten rings have been used together, but the number is reduced in the later forms, and better effects obtained with four rings than with a greater number. The wires of all are connected in series to a commutator, like that of the Gramme. The arrangements for charging the field magnets are described § 902.

884. THE EDISON DYNAMO machine should be mentioned because it is a great deal used, and has been made in large sizes. It has, however, no specific principle: its armature is to all intents a Siemens armature, § 874. Its features consist in good mechanical and electrical arrangement of the parts: the iron cylinder is replaced by a series of thin iron discs which constitute a laminated cylinder, in which currents are not set up, and which can allow circulation of air, if so arranged: the wires are replaced by bars of metal fixed at each end to plates of metal which connect them in proper order.

The field magnets are, in principle, exactly those of Fig. 101, consisting of plain horseshoes with wide inclasping pole-pieces: at first they had two peculiarities, the use of compound arms as in the early Gramme machines, and the great length of these. This latter appears to have been adopted in a true course of evolution from Mr. Edison's really original tuning-fork idea of a machine. They were wound on the shunt principle, with a wire of considerable resistance as compared with the armature.

Dr. Hopkinson has recently introduced great improvements in the construction, principally by giving up these special features of the field magnets, increasing their mass, and reducing the length and substituting single arms for the multiple ones, as also in attaining considerable reduction of the speed of rotation required to attain the same result, and applying the compound shunt and series system to the charging of the field magnets, in order to make the E M F self-regulating.

885. The *Gordon* and the *Ferranti-Thomson* machines are of the alternating type. They are claimed to be very effective for purposes of lighting, but will probably only be available for large installations, and their description, to be of any service, would occupy more space than can be spared, and would be

of interest only to those who can readily obtain the same of a more complete character than would be suitable here.

886. DIRECT AND ALTERNATING MACHINES.—The earlier machines were all alternating generators, requiring a commutator to convert the impulses into a current of uniform direction; in the Alliance machine this commutator was dispensed with, to great advantage in economy, § 831. The Pacinotti type generates direct currents. Later machines again, such as the Ferranti-Thomson, the Gordon, and others, produce alternating currents. It is a question which system gives the best results, and the difference deserves consideration.

Direct currents are essential in electrolysis, and in the maintenance of magnetism in iron. Therefore, a self-exciting dynamo must give a direct current.

Commutating alternate currents is bad economy, and attended with heavy loss of current, and destruction of the metal by sparks.

887. *Alternating current machines* are simpler in construction, and more easily furnish a high E M F.

They can be used with suitably constructed arc lamps, in which solenoids are used to control the motion instead of electromagnets. They are essential for the "candle" lights, in which two carbons are required to burn equally, so that special machines are made to convert the direct current into an alternating one, while adding to its force. Incandescent lamps have a longer "life" with alternating currents, as there is a destructive action exerted by the current, resembling electrolysis, though probably of the same order as the results obtained in Crookes's "experiments on the fourth state of matter."

888. But *alternating currents involve inductive resistances*, and will therefore be more difficult to insulate and distribute; they cannot excite their own magnets; they cannot work any existing motors, and it is doubtful if motors without iron can be made to work economically.

On the whole, it would appear that for local, self-contained applications for lighting purposes, the alternating current may be the best; but for general use, and for large applications, it is retrograde progress to employ this type of machine.

889. FIELD MAGNETS.—For the sake of *economy*, they should be constructed as to size and wire, so that they shall nearly reach the limit of saturation at the fullest limit of work.

For *steady working under varying conditions*, they should be well within the limit of saturation.

For *automatic adjustment*, they should not approach that limit even at full work; they should still be in conditions which increase magnetism proportionately to current, § 944.

The *length* for a given weight is governed by the same laws as those for proportions of electro-magnets § 939: long magnets have more residuary force, but length is a disadvantage when it exceeds the limit at which the quantity of wire to be used is most effective.

The *pole-pieces* should contain one-quarter of the iron of the magnet, and the arms should be rather of one mass than divided into several, and should therefore be of a thin and broad section, so as to be fully influenced by the coils, rather than circular.

The *winding of the wires* is arranged on different systems to suit special requirements.

890. *Separately excited* machines are independent of any variations of the work doing. They are those with permanent field magnets, or those excited by a separate machine, which is necessary when the machine itself is one for alternating currents, though the two machines are in some cases driven upon one axis. The Wilde machine, § 827, is of this type, as also are the Gramme and Lontin systems used for lighting.

The Ladd machine, § 830, and the early Gramme machines were a step from separately excited to the self-exciting form, because they had a distinct armature to feed the field, but it was actuated by the field magnet itself, see § 830.

891. *Self-exciting machines*, in which the principle of accumulation, § 828, is fully utilized, are of several different orders of field magnets. They are made as series and shunt machines, and as different combinations of these. Fig. 105 shows the field magnet separately excited, Fig. 106 the series circuit, and Fig. 107 the shunt system.

Fig. 105.

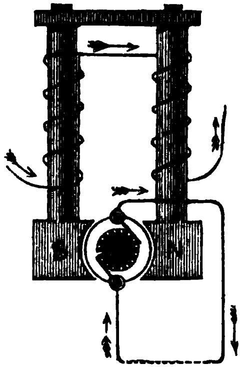


Fig. 106.

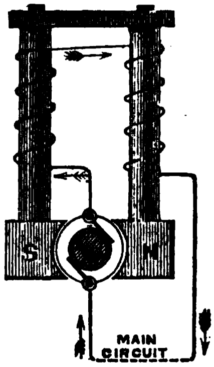
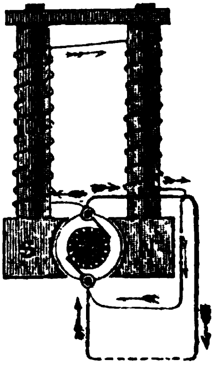


Fig. 107.



(1) *Series* machines are those in which the current passes from the + collector of the armature, round the field magnets, to the + terminal, the − terminal being connected to the other collector. Therefore, the current passing the field magnets depends on the external resistance. The effect is that as the conditions for current in the work increase, so the field is more powerfully charged and the machine gives more current as it is called for. They are therefore admirably adapted to such work as electro-metallurgy, for a machine which will work a room full of vats may plate a single spoon, while a separately excited machine would require most careful control by adding resistances in such a case.

On the other hand, a series machine is difficult to start against a large resistance, and may require a temporary shunt to the work in order to charge the field magnets. They are also liable to reversal of polarity by counter currents. Several devices are employed to correct these tendencies: thus Weston employed a rotating mercury governor by which the outer circuit is cut out until a certain fixed velocity of rotation is attained, when it is automatically put into the circuit. Gramme employed an electro-magnet, or a connection held up by the field pole for the same object, so that the early current should all go to the field until a sufficient force had been attained to secure regular work.

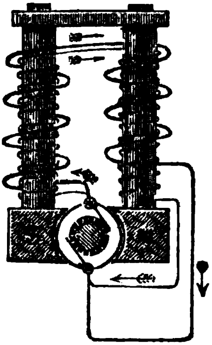
(2) *Shunt* machines divide the armature current between the field magnets and the external work: thus at the + collector two circuits start, one going to the + terminal, the other round the field magnets to the − collector which is also connected to the − terminal. This controls the strength of the field as required, because the field wire and the armature are so balanced in resistance that with open circuit only current enough is generated to charge the field; the work, as it lowers the external, and therefore the total resistance, allows more current to be generated in the armature, of which the field wire gets its increasing proportion—increasing, that is, as to current traversing the field, while a decreasing proportion of the total current, therefore becoming more economical as the machine approaches its full work. But this regulation, while automatic, is irregular, and will not suit applications requiring perfect steadiness at all parts of the work, as in electric lighting.

(3) *Shunt and Series* machines combine the two systems, as shown in Fig. 108; one wire, the shunt, is as just described; the second, the circuit wire, instead of going to the + terminal direct, is first taken round the field magnets, as well as the other and then to the + terminal, so that at all times the *whole of the armature current* traverses the field magnets; but the

proportion of it in the two wires, and the total current produced, depend upon the external resistance.

This arrangement has been employed in various machines, as in the Brush machine, where a long fine wire was wound on the iron as a shunt of high resistance, and called a "teaser." But recently it is coming into more definite use with its relations carefully balanced in order to secure a varying field force which will adjust the E M F to the requirements of a varying circuit. It is thus employed in the Crompton-Kapp Bürgin compound dynamo in order to provide a fixed current in every lamp connected, whether only one lamp or the whole system is at work.

FIG. 108.



M. Deprez, Messrs. Ayrton and Perry, and Mr. Hopkinson and others have also used this and various combinations of the shunt, series, and externally exciting systems in order to obtain the results described § 900.

892. QUALITY OF IRON.—*Armature cores* should be made of the softest wrought iron, though good malleable castings are employed in some cases: the greater the rapidity of the changes which occur, the more essential this is, as any tendency to residual magnetism will lower the efficiency. For *field magnets* different conditions exist: in them *residual magnetism is essential*, so that ordinary cast iron may be used. On the other hand, E M F depends upon the "magnetic intensity" and this upon the *capacity* of the iron, § 947. This varies very greatly in different irons, being greatest in the purest and softest wrought iron. Both theoretical considerations and experimental results indicate that the highest effect will be obtained from soft iron cores to take up magnetism from the current, good malleable castings for the pole-pieces, and massive connecting pieces of hard cast iron to serve as reservoirs of magnetism: in some cases steel plates have been combined with soft iron for this purpose of maintaining residuary magnetism when the machine is not running.

893. EFFECT OF DIMENSIONS.—Many attempts have been made to produce *small dynamo-machines*, but none are satisfactory. Machines were made by Ladd, § 830, to be worked by hand, but they could not be called small machines, and my experiments showed that they only utilized one-tenth of the power expended; it is said that some machines have utilized one-third: but good dynamo machines return 80 and some claim 90 per cent. return.

Those who wish to possess small machines to substitute for batteries will do well to confine themselves to the magneto type with a powerful steel field system. Such are easily made on the Gramme type with cast-iron pole-pieces fitted with Jamin's magnets, say 18 inches high; these are made of successive layers of hoop steel properly let into and riveted to the pole-pieces, and generate a powerful field. See also § 910.

It has been calculated mathematically that the power of dynamo machines will increase as the fifth power of the linear dimensions (that is any measure, such as height, which is equally altered in every other, so as to make the smaller a true model of the larger). The weight of materials used would only increase as the cube, that is the third power, so that increased size would be a very great and growing advantage, especially as cost of construction would not increase so much as the weight; this law, if true, would explain why small machines cannot be made efficient. But the result is doubtful; large masses of iron do not magnetize so well as smaller ones, and if the magnetism were equally intense the power of the magnet would only increase as the weight, or as the third power, in which case a machine of doubled weight would only do the same work as two machines of half its weight.

M. Deprez has compared two apparatus, alike, but one of doubled linear dimensions, in which the weight was eightfold (that is d^3) and the force sixteenfold (that is d^4). These were without iron: when iron was used in the armature the force was only fifteenfold, due no doubt to the cause just mentioned as to iron. This would indicate that though there is a gain of power beyond the increase in weight, yet it is a gain not so great as the fifth power, and probably varying with increased dimensions in some ratio yet to be ascertained.

894. *Relation of Speed.*—In the simple magneto or separately excited machine the E M F is proportional to speed, so that with a constant for each machine, "speed" would replace E in Ohm's formula. In self-excited machines E M F grows at a much greater rate than the speed.

But speed is of necessity limited, and it is much more convenient to work at a fixed speed; it is also proved that every individual machine has its specific speed at which it does its best work, and at which, according to M. Deprez, the E M F will be proportional to the current in the field magnets, provided of course that the range is well within the limit of saturation.

895. THE E M F OF DYNAMOS.—The first essential for success in electric lighting is absolute steadiness. (1) There must be no

fluctuation in the light itself: this means uniform E M F, and necessitates perfect steadiness of motion in the driving engine, to attain which the engine ought to have a large margin of power so as not to be near its limit of work; it should have a heavy fly-wheel, and a fly-wheel should be attached to the axis of the dynamo itself. (2) The available current should not be either increased or reduced by the sudden turning on or off of other lights; this means that there should be maintained a constant E M F at the terminals of each lamp. This requirement has modified the aims of machine designers, because it involves more complex considerations than the mere generation of a defined E M F, which was all that was at first aimed at, that is, to make the dynamo represent and replace so many battery cells.

896. *Relations of Internal and External Resistance.*—As in batteries, there is a law connecting these to useful work. Economy means that the greater part of the resistance should be external, and that it should be of the nature of *work*, § 454. The laws of distribution of potential, § 401, show that only the E M F which is expended in this "work resistance" is of use; the rest is expended in driving the energy to the point of application. Therefore we have to consider four distinct divisions of the E M F set up in the dynamo, each of which, multiplied by its own current, gives the relative energies.

(1) The E M F at the terminals of the working apparatus, say the electrodes of a plating vat, or the connections to lamps: this is *the energy utilized.*

(2) The E M F at the terminals of the dynamo, which includes the first, and also that expended in the conductors. The difference of 2 − 1 is the *expenditure in transmission.*

(3) The E M F in the field magnets, expended in maintaining the force of the field.

(4) The E M F at the brushes, that generated by the armature, of which the others are portions. The energy expended in the armature itself is given by $C^2 \times R$.

897. *Varying external work* alters the relations of these divisions. In a separately excited machine the E M F is as the speed; that is to say, a constant speed gives a constant E M F, under all variations of external work; but this is a total E M F, like that of a battery, and varying external work will alter the current.

Take as example an electrotype cell, intended to work up to 50 square feet of surface, with a solution giving resistance of half an ohm per foot, and requiring a current of 10 ampères per foot. The full R of the vat would be $\cdot 5 \div 50 = \cdot 01$ ohm and by the usual law of equal internal and external resistance, the machine should have also $R = \cdot 01$, being a total of $\cdot 02$. The current being $50 \times 10 = 500$ ampères, we have as E M F $500 \times \cdot 02 = 10$ volts, required to be generated in the armature. Now if this is a *magneto* machine, or a battery, what happens when the work is reduced to 1 plate? We have then $R = \cdot 01 + \cdot 5 = \cdot 51$ and $10 \div \cdot 51 = 19 \cdot 6$ ampères instead of the required 10, so that unless a controlling resistance were interposed the work would be injured.

898. The effect is even more serious with incandescent lights, which scarcely admit of control except at the engine room. Let us assume, for convenience of figures, the full work as 100 lamps in multiple arc, each 100 ohms R, and requiring 1 ampère per lamp to work them: this is $R = 1 \cdot$; and with the dynamo $1 \cdot$ we have 2 ohms R, and a current 100 ampères, requiring E M F 200 volts. When all but 1 are turned off we have $R = 1 + 100 = 101$ and $200 \div 101 = 2$ ampères instead of 1. But as the heat is as C^2 we should now heat that carbon thread to four times its intended temperature and probably destroy it; if light is as C^4 the lamp would suddenly rise from 20 candles to 160.

899. *Constant current* is required in some cases, as when lights are placed in *series*: here therefore the current would rise in the circuit, as the resistance of one or more was removed, unless an equal resistance were interposed in its place: but this (which was proposed and patented several times as a means of regulation) would involve equal expenditure of energy whether the current were doing useful work or not: the lamp would cost the same whether giving light or turned out.

900. *Constant E M F at the terminals of the work*, § 896, is therefore the desideratum, not constant E M F generated by the machine in the armature ring. With lamps in series, this means a *constant current* generated at the terminals of the machine irrespective of changes of resistance: with lamps in multiple arc, it means a *current variable inversely as the external resistance*, or *as* the conducting capacity, i. e. *as the number of lamps* opening paths of conduction.

Both require *variable E M F* generated in the armature. Now E M F is changed by

(1) Variation of speed.
(2) Varying the strength of the field.
(3) Altering the number of turns of wire in the armature.

The second is the practicable mode. It may be effected in magneto machines by arranging an iron armature to slide over the arms along the length; or made to either move across the field, or to approach or recede: all these mean *short circuiting* or *shunting* the field poles, which is wasting power: but these plans have been used in large machines, or at all events proposed, and medical magneto machines are commonly fitted with a movable armature for this very purpose.

901. *Magnetic force varies* in electro-magnets according to two ratios: (1) as the number of turns of wire; (2) as the current passing. We may put the two ratios together and say it *varies as the current-turns;* or carrying out the regular evolution of technical terms, we may say: *In a given magnetic system the force varies as the ampère-turns.* See § 942.

The number of turns cannot be conveniently varied, but the current passing in them can be altered in several ways, and so the "*ampère-turns*" will, by this variation, modify the strength of the field, and the E M F generated.

In *separately excited* machines, this is effected by altering the current from the exciter, which is effected by means of variable resistances interposed by an attendant or automatically. But it is best effected by combining the shunt and series system of winding, § 691 (3). This plan has been used by several makers of machines; but I will explain it by the machine patented by Messrs. Crompton and Kapp.

902. Crompton-Bürgin Compound.—The following extract from the specification will explain the principle and construction.

"One method of carrying out this compound winding is to take a machine having an armature resistance of say 0·1 ohm and wind on its field magnets, next to the core, sufficient No. 5 B.W.G. wire to give a resistance equal to that of the armature, and couple the same in series circuit with the armature. [This is the series circuit in which the external work is included, § 891 (1).] Outside these coils we wind on sufficient ·057 inch wire to give a resistance of from 20 to 30 ohms; we couple this from brush to brush [this is the shunt circuit § 891 (2)]. Such an armature we prefer to drive at such speed that the E M F, when the R of the outer circuit is infinite (that is, open) will be about 65 volts. It will be found that if the external circuit be now closed through resistances varying from infinity down to 0·75 ohm, so that the current varies from 2 ampères up to 80 ampères, the electromotive force between terminals will remain nearly constant at 65 volts. Moreover that the magnet charge or extra current of the short length of low resistance coils will be so small, that 40 or 50 lamps may be switched simultaneously out of the main circuit, without producing any momentarily hurtful increase of current in one lamp left in circuit."

903. Ratios of Resistances.—The relative proportions of external resistance to that of the field magnets and armatures have been greatly varied as the subject has been studied. According to the formulæ of Sir W. Thomson, in the British Association Report 1881, the resistance of the field magnets

should be a little less than that of the armature in the case of series dynamos. For shunt machines the formula is

$$R = \sqrt{F \times A} \text{ and } F = R^2 \div A$$

R is the resistance of the external circuit.
F „ „ field magnets or shunt.
A „ „ armature.

In the early machines of the Gramme type, the field magnets had about seven times the resistance of the magnetizing, or the working coils which were nearly alike.

The actual resistances will vary with the conditions and with the quality of iron and form of the magnets, and the effect of small variations is studied by means of the characteristic curves showing the actual working of any particular machine.

904. CHARACTERISTIC CURVES. — These, first employed and named by M. Deprez, fulfil for dynamo machines the same purpose as the indicator diagrams do for steam engines. They indicate the most advantageous speed at which a particular machine should be run; they also show whether the armature and field magnets are suitably proportioned, and adequately wound with wire.

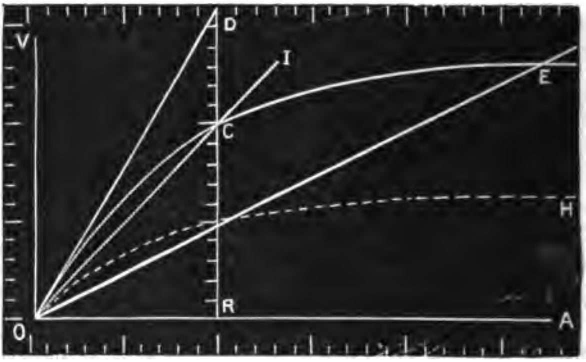
Taking the simplest form of a separately excited machine, with a definite current sent into the field magnets, the current produced at different speeds in a fixed resistance is measured: the speeds being set off on a vertical scale, and the current on a horizontal one, lines from these give a series of points through which a line can be drawn, which will be a curve corresponding to those described § 944, and due to similar causes; it represents in fact the E M F generated at the different speeds. Each different current sent into the field magnets will produce a different curve, as this varies one of the causes of the E M F, § 900 (2).

Again, driving at a fixed speed, but varying the field current, which will then be the element of the vertical scale, a similar curve will be obtained, different for each speed. But having obtained a curve corresponding to one speed, the curves of other speeds can be constructed from it by modifying the ordinates that form the curve in the ratio of the two velocities, as shown in the dotted curve of Fig. 109. The effect of a change in the wire of the field magnets may also be ascertained in a similar way, varying the ordinates in the ratio of the number of turns of wire, providing the wire in each case occupies the same position and space upon the magnet.

905. Such a characteristic curve is shown Fig. 109 with illustrations of the uses which can be made of it.

The curve O C E is that of a uniform velocity, derived from the line O V which is that of field magnet currents, velocity, or E M F as the case may be, and O A the line of current generated, both in equal parts. It will be seen that the curve rises until the field magnet is saturated, when there is no further rise of E M F, so that this curve depends upon the quality of iron in the field magnets, and in the armature.

Fig. 109.—Characteristic Curves.



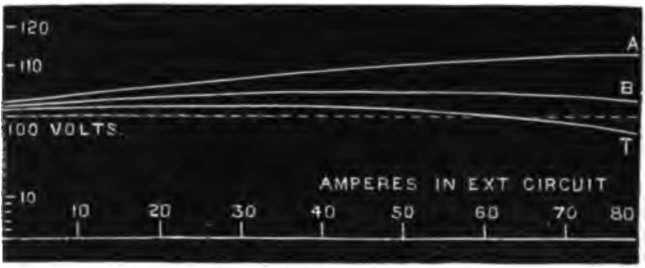
906. The *resistance* corresponding to any current may be calculated from this curve. Raise the line R D at any part of the line O A, then the length O R will give the space corresponding to 1 ohm, provided the line O V is divided in volts upon a scale equal to that of ampères on O A, because from the relations between E M F and current in Ohm's formulæ, R is represented by the tangent of the angle formed at O by the line drawn from the point of the curve corresponding to any current. Thus if O R measures 1 ampère, and R C 1 volt of E M F, the line O I cuts R D at C, which being equal in length to O R is 1 ohm upon the scale of R D, which is shown for convenience upon the same scale as the lines of E M F and current.

If the resistance be extended so far that the line from it to O passes altogether outside of the commencement of the curve, we have the limit at which a *series* machine will fail to generate current, § 891 (1), as shown by O D.

907. The proper *characteristic* for a machine to give the results described §§ 899 and 902 would be, not a curve, but a straight

horizontal line for the external circuit: Fig. 110 gives the curves of a Crompton-Bürgin compound machine of the D_6 type.

FIG. 110.—CHARACTERISTICS OF COMPOUND BÜRGIN.



This figure shows the E M F in the different divisions of the circuit: but the E M F under 90 volts is omitted, and the current is on a scale double that of E M F.

(2) The resistances are, while hot, armature, ·205; series field circuit, ·148; shunt field circuit, 34·24; and external circuit, ascertainable by E ÷ C or say, with 10 ampères current 10·5 and with 80 ampères 1·16 ohms. The following comparison will show the distribution under those conditions.

	In external work.	Armature.	Field Magnet.		Total.	Per cent. used in work.
			Series.	Shunt.		
Current, Ampères	10· 80·	13·11 83·05	10· 80·	3·11 3·05	.. ..	.. ..
Energy, Joules	1050· 7424·	85· 1414·	15· 947·	332· 319·	1432· 10112·	73·3 73·5

Of course there is also a loss by the friction of the machine, the figures relating only to the actual electric energy generated and expended, and comparable with batteries, which would give a useful work of 50 per cent. instead of 73·5, the rest being lost in internal resistance, while this dynamo would give about 63, allowing about 10 per cent. for the mechanical friction, which is the average in practice.

(3) The *efficiency* of a dynamo machine is often reckoned from its capacity as a converter of mechanical energy into electrical, that is by the formula $C^2 \times R$. But the electric

energy expended *within the machine* is as much waste as the mechanical friction.

The *true efficiency* is represented by the ratio of the *energy in the external* circuit, to the mechanical energy expended in driving; that is, it is related to the curve T, not to the curve A, Fig. 110, which represents the total conversion. If we call the horse-power employed in driving, 100, then we shall generally have about 10 to 13 per cent. absorbed in friction and local currents which would reduce the efficiency of the particular Bürgin, as stated above, to 63 per cent., while the various tests made at public trials show that this true efficiency as developed in different machines actually ranges down to 30 per cent. only. The efficiency is greatest in large machines, and when the machine is used under the conditions for which it is designed; so that mere figures of comparison under fixed circumstances are apt to mislead.

908. ELECTRO-MAGNETIC ENGINES.—The earliest and simplest form of electro-motor is the rotating mercury break which was used for induction coils. Between the arms of a horseshoe permanent magnet is a wooden block on the face of which is a circular groove, divided by two thin plates of ivory opposite the poles, into halves which are connected by wires to the terminals; in the middle is a tube in which a steel pin can be placed, on the upper end of which is fixed a bar electro-magnet, so as to allow it to rotate between the magnet poles; the ends of its wires descend so as to just clear the ivory slips, and dip into mercury contained in the groove which rises above the level of the divisions: therefore, the magnet reverses its polarity as it passes the pole, is then repelled till the attraction of the other pole comes into play (or more truly the bar travels along the lines of the electric field between the poles), and so a continuous rotation is produced: more power would be generated by a second magnet at right angles, and also by increasing the number of electro-magnets. We have in fact here the very stages by which the earlier forms of magnetic engines were developed.

Then we have an iron armature on a lever playing between two electro-magnets alternately excited, or an electro-magnet similarly placed and alternately reversed, and this oscillating motion transformed into rotary motion, as in the steam engine, by a crank operated by a prolongation of the lever. Another system was based upon an iron bar attached to the lever, but plunging into a coil. But all these forms utilize but a small part of the energy expended, mainly because the action is effected at too great distance.

909. *Good dynamo machines make the best motors*, but though they are thus reciprocally convertible, it does not follow that the best generator will be the best motor: on the contrary, there are functional differences which require to be met in different ways, and particularly in the proportioning of the parts, and the relation of the field and armature systems; in the dynamo, the magnetism of the armature is a result of the field, but in the motor it has its own independent existence. Therefore, it is advisable to so adjust the wires of field and armature as to make the two fields of equal intensity, and to so arrange the poles generated (whose position depends upon that of the commutator brushes), as to cause the action to result mainly from the attractions set up by the *approaching* poles, and not from the repulsion between similar poles, because these latter tend to reduce each other's strength, while the others assist each other.

Motors should have the moving parts light, so that they may rotate rapidly, which is a prime condition of efficiency, and there being less momentum, they start and stop easily.

910. Motors, like dynamos, and in fact all engines, are of two types, distinguished by the production of alternating and continuous currents in the armature. It is evident that an alternating action, in electricity as in mechanics, must involve a greater loss of energy than a continuous one; but this does not settle the question of final utility, for in the steam engine it is found better to employ the alternating process, rather than the rotary engines. At present, it appears that for small motors and light work, alternating current machines can be most usefully employed and permanent field magnets used; while electro-magnets and continuous current armatures are most economical and best suited to large machines.

911. *Alternating current* motors are all based upon Siemens' core, in fact they are nothing but small Siemens machines, as stated § 865.

(1) *Deprez* has a remarkable divergence from the ordinary plans, in that he places the armature not in the interpolar space where a concentrated field is produced, but *lengthwise between the arms of the magnet*, which is a permanent one. It is true that the magnetic lines do cross the space between the arms to some extent, as Fig. 32, p. 94, shows: it is also true that the presence of the armature would tend to draw the lines into this space, and prevent the extension of the magnetic force towards the poles: but this would tend to a strong molecular disturbance in the magnet at each semi-rotation of the armature, and it would seem better to use the normal field formed at the ends.

(2) *Ladd* and also *Browning* prefer to make the field magnet circular, so as to resist the formation of the cross lines, and give length to the magnet, the field space being, in fact, a circular opening in this circle.

(3) *Trouvé's* motor is simply a Siemens machine with electro field magnet, and the armature ends elliptic instead of circular.

(4) *Griscom's*, which is made so small as 2 lbs. in weight, is the same as Trouvé's, but the field magnet incloses the armature.

912. *Continuous current motors* are derived from any of the dynamo machines, and it appears that the Gramme ring is best adapted to the purpose.

(1) *Ayrton and Perry's* motor is really an inverted Gramme machine, with the armature ring made stationary, and modified in construction to resemble the armature described in my own patent of November 1878, which is indeed the Pacinotti ring constructed of disks of sheet iron instead of solid metal, while their field magnet in the interior is a Siemens core. The object of making the armature fixed is explained in § 909; as the magnetism is travelling, it is not so strong proportionally as that of the field system, in which no changes occur: to compensate for this it is made more massive.

(2) *De Meritens*' motor is an armature closely resembling that of Ayrton and Perry, but is movable as in the usual dynamo machines; in fact it is simply a small dynamo of which not only the armature but also the field magnet is described in the patent just mentioned. It is a circular electro-magnet inclosing the armature, and forming two poles just as in the latest forms of the Griscom motor. Really, these two differ in principle in the fact that in one the Pacinotti armature is used, and in the other, the old Siemens core; so that one is a continuous action, while the other is alternating.

913. Where two dynamo machines A, B, are placed in circuit together, with a galvanometer to manifest the actions, when A is rotated it generates a current which passes into B; if this is prevented from moving, the galvanometer will show a current due to the E M F corresponding to the speed of A, while B plays the part of a simple resistance.

If B is also rotated, and the connections are such as to oppose the two machines, we may have no current at all, and the machines will require no more power to drive them than corresponds to the mechanical friction.

If B is left free it will rotate itself as a motor, and the galvanometer will show a current less than that produced when B was not in motion: the reason is that the motion of B, however produced, generates an E M F which, when produced by the current, is an opposing E M F, corresponding to the counter E M F set up in a voltameter.

914. *The efficiency of motors* may be ascertained by the – E M F they generate. Thus current being passed while the machine is at rest and its value noted, the efficiency will be related to the reduction of current when the machine is allowed to run free, doing no work, for if the machine were perfect it would generate a velocity closely approaching that which would generate an E M F equal to that producing the current: this being of course impossible, any current actually passing measures that expended by the machine in internal work.

The essential consideration as to the value of a motor is its *efficiency*, that is its return expressed as

$$\frac{\text{Energy produced}}{\text{Energy supplied}} = \text{Efficiency.} \qquad \frac{\text{H.P.}}{\text{C} \times \text{E} \times \text{J}} = \left\{ \begin{array}{l} \text{percentage} \\ \text{returned.} \end{array} \right.$$

The energy supplied being measured by the current used in driving, § 330, partly lost in heat in the wire and iron, partly in ordinary mechanical friction; the energy produced being measured by the weight lifted, or by a dynamometer.

915. The next consideration is the relation between efficiency and the cost or convenience of the machine, as related to its size or weight. It follows that the *efficiency* of motors with steel permanent field-magnets should be higher than those with electro-magnets, but that as to the second consideration the electro-magnet has the advantage.

916. Profs. Ayrton and Perry give the efficiency of various motors as follows:—

Motor.	Weight in lbs.	Res.	Current.	Revs. per min.	H.P.	Efficiency.
Griscom	2·5	1·1	3·9	513	·00225	·0542
"	"	"	4·9	2520	·0110	·126
Gramme armature }	8·03	·443	16·8	803	·0176	·0876
Siemens field }	..	..	16·9	2853	·0625	·199
Do. {	30·8	·973	5·4	932	·0272	·296
{	..	..	6·7	2527	·0738	·289
Jablochkoff	20·9	1·17	8·1	609	·0107	·0373
Ayrton and Perry ..	37·	·2	25·9	720	·14	·317
" ..	"	"	21·2	1880	·215	·383
De Meritens	72·	·850	10·6	860	·154	·51
"	"	..	8·4	2000	·75	·50
Siemens	519·	..	..	906	4·96	·746

The figures do not relate to the cost of *putting the energy into the motors.* It may be generally taken that this is equal to that expended in the motor itself, so that the actual return for energy expended would be about half these values.

These figures show the increasing efficiency of the larger machines, and the advantage of high speed.

917. *The direction of rotation* of the axis depends on the position occupied by the armature poles as compared with those of the field. Therefore a dynamo machine used as motor would not reverse its direction upon reversal of the current, because both sets of poles would be reversed: reversed motion is produced by the reversal of the current in the armature or field alone; usually the armature, which is intended to undergo changes of magnetism.

The *position of the commutator* contacts in motors is different from that of generators, being either on the central line, or with a backward "lead," because the pole, being generated by current delivered at the contact, attains its maximum a little in advance of this point.

918. Motors should always be worked on the *multiple arc* system, so that there should be no mutual interference, but all being supplied and adapted to a constant E M F, each will close its own circuit, and call forth the required current from the generator, as described § 900.

919. COST OF WORKING.—The utility of a machine, and the possibility of its employment (where conditions of convenience do not override all others), depend upon *the cost of a unit of energy* delivered by it, and this is based upon (1) the cost of the source of energy; (2) the efficiency of the conversion. Now the oxidation of 1 lb. of coal gives the same energy as that of about 7 lbs. of zinc, which costs some twenty-four times as much per pound, so that the energy of the source is in one case 150 times as costly as the other, and no amount of efficiency can make the cost of energy produced comparable in cost. For this reason *it is quite impossible for any electro-motor to be worked with a battery except at enormous cost,* as long as the battery product is valueless.

Thus Joule calculates that, under the most favourable circumstances, an electro-magnetic engine would consume 75 lbs. of zinc in a Daniell's battery to maintain 1 horse-power for 24 hours. Now Table V., p. 119, shows 20 equivalents per lb. of zinc, and the Daniell's force is 1·079, therefore 75 × 201 × 1·079 = 16,266 equivolts; a horse-power for 24 hours is 10,168 equivolts, and twice that amount at least is required; but taking these figures and setting the cost of the battery as only 4*d.* per lb.

of zinc, we have 25*s*., while 96 lbs. of coal, costing at 20*s*. per ton, 10·29*d*., would in a common steam engine do the same work.

It is important that this exact mode of estimating costs and possibilities should be clearly understood, and therefore I will work out the subject and show the cost of energy per equivolt, § 527, as comparable with that of batteries, p. 171, and per 1000 joulads, which is one proposed unit of charge for electrical energy delivered.

920. ENERGY OF FUEL.—According to the table, p. 319, the energy of carbon is 9624 foot-lbs., or 2·0594 equivolts. But in most treatises on heat, it is usual to value the work of fuel, &c., in terms of units of heat, generally that amount of heat which will raise 1 lb. of water 1° Fahr. in temperature: such values can be converted into the equivolt by dividing by 6·0523, or by multiplying by its reciprocal ·166 or Log. $\bar{1}$·2180099. On this system, according to Favre and Silbermann, the value of carbon per lb. is 12,906 units, and of hydrogen 62,535. According to the Government experiments on coal, the average of English qualities may be taken as—

Carbon, per lb. .. .. ·812 × 12905 = 10480
Hydrogen (available), per lb. ·041 × 62535 = 2564
Equivolts, per lb. .. .. 2154·9 = 13044

Taking the price of coal as 20*s*. per ton, as an average figure from which actual cost is readily derived under any circumstances, we get the cost of coal per lb. ·1071 of a penny, and per equivolt ·0000497. We must next consider the proportion of this actually utilized in ordinary steam engines. This will depend upon their consumption per "indicated horse-power," and this varies from 2½ lbs. per hour in the best engines to 5 and 6 in common ones.* A horse-power is 33,000 foot-lbs. per minute or 1,980,000 per hour = 423·7 equivolts; if, then, we take 4 lbs. of coal per hour as an average consumption, this brings the practical mechanical equivalent of the pound of coal to 105·9 equivolts, and the practical cost of steam-power per equivolt ·00112 of a penny. On these data the average steam engine utilizes only one-twentieth of the potential energy of its fuel, or an efficiency of ·05 as compared with the figures § 916, or rather with the half of those values.

---

* The indicated horse-power is usually employed as the measure of work and merit of an engine, but it is not really so, as it does not allow for the friction of the engine itself. The correct value can be ascertained only by some kind of dynamometer which measures the actual mechanical energy exerted at the driving pulley of the engine per indicated horse-power developed in the cylinder, as this latter measures the proportion of energy of the fuel transformed into pressure on the piston by the agency of the boiler and cylinder.

A man's power is usually taken as one-sixth that of a horse-power, or 70·6 equivolts, and at 8*d*. per hour, costs per equivolt ·1133 of a penny.

921. Gas as Fuel.—A ton of average coal gives 9600 cubic feet of gas of ·450 sp. gr., which is 331 lbs. of gas per ton; about 1300 lbs. of coke are also produced, and if we allow even one-third of this as consumed in the furnaces we may consider we get about 12 feet of gas for each pound of coal consumed, that is, 100 feet represent at most 8 lbs. coal. This calculation gives the cost of potential energy in gas per equivolt as the same as in coal, assuming equal energy for equal weights; but the energy of gas is really greater than an equal weight of the same materials in the solid state, the energy of part of the fuel consumed in the furnace having been employed in passing it into gas. There is some doubt as to what is the real energy of gas. Siemens, at the British Association meeting, 1882, stated it as 22,000 ordinary heat units, while others give it as 15,000 per lb., average coal being 12 to 13,000. I will use the mean of these values for present purpose, or 50 per cent. over equal weight of coal.

We thus get a value of 25,858 equivolts per 100 feet, which at 3*s*. per 1000 is ·000140 for cost of potential energy, which compared with line 1 shows that gas when employed as a source of heat is nearly three times as costly as coal. Now a good gas engine develops 1 horse-power for 21 cubic feet per hour, which gives us an efficiency of ·117 or more than double that of steam engines using 4 lbs. of coal per horse-power. This still leaves the cost for gas 75 per cent. greater than that for coal, with the result of really a much lower cost, because the steam engine involves labour in firing and attention, while in the gas engine this is avoided.

922. Cost of Energy.—We may now tabulate all these values in the same manner as was done p. 171 for the cost of energy derived from batteries. As there, nothing is taken into account but the materials.

COST OF MECHANICAL ENERGY, IN PENCE.

See §	Source.	Equivolt.	1000 Joulads.	H.P. hours.
1. 920	Coal at 20*s*. per ton *potential*	·0000497	·0000079	·0211
2. „	Steam engine at 2·5 lbs. p. H.P. hour	·0006319	·0000997	·2678
3. „	„ 4 „ „	·001011	·0001590	·4284
4. 921	Gas at 3*s*. per 1000 feet *potential* ..	·0001389	·0000222	·0590
5.	Gas engine at 21 feet per H.P. hour	·0017845	·000281	·7560
6. 920	Man's power at 8*d*. per hour	·1133	·017874	4·8066

Electro-magnetic motors will cost according to the sources from which their current is derived, § 923, and will be as

$$\frac{\text{Cost of electric energy}}{\text{Efficiency of motor}} = \text{cost of mechanical energy.}$$

This is worked out for various cases § 924.

923. Electric Energy in the circuit will cost as

$$\frac{\text{Cost of source, above}}{\text{Efficiency of dynamo}} = \left\{\begin{array}{l}\text{cost at terminals}\\ + \text{ loss in conductor.}\end{array}\right.$$

When distributed, it is proposed to make the charge for it upon the 1000 volt ampère-hours as a unit, which would be equivalent to 3,600,000 joulads.

The following table shows the cost according to the source of mechanical energy, and the efficiency of the dynamo machine in its external circuit, § 907 (3).

COST OF ELECTRIC ENERGY, IN PENCE.

See §	Electric Source.	Equivolt.	1000 Joulads.	Horse-power.
1.	Proposed unit, at 1 penny ..	·0017606	·0002778	·7459
2.	„ charge 7*d*.	·0123242	·0019450	5·2216
3. 922	Steam engine, 2·5 lbs. coal. Dynamo, efficiency ·70	·0009029	·0001425	·3826
4. „	Do. 4 lbs. „ „ ·63	·0016049	·0002532	·6800
5. „	Gas engine „ ·63	·0028321	·0004467	1·2000
6. 171	Batteries, nitric acid	·1863	·0029394	78·936

The battery cost is calculated from the nitric acid values in the Table, p. 171, averaging them and allowing for half the energy being absorbed in internal resistance. It explains at once why electro-motors were impossible when depending on battery currents.

924. Work from Electro-Motors.—The two preceding tables

COST OF HORSE-POWER FROM ELECTRO-MOTORS.

See §	Source of Current.	Efficiency of Motor, § 916.		
		·20	·50	·75
923	Battery at ·1863 per equivolt	394·68	157·87	105·25
„ l. 2	Distributed at 7*d*. per unit ..	26·18	10·44	6·96
„ „ 3	Steam at 2·5 lbs. Dynamo ·70	1·91	·77	·51
„ „ 4	„ „ 4 „ „ ·63	3·40	1·36	·91
„ „ 5	Gas engine „ „	6·00	2·40	1·60

enable the cost of work from these to be calculated. The cost of energy in the conductor is to be added to this.

925. TRANSMISSION OF ENERGY.—This subject, as to which great expectations have been put forth, naturally comes to be considered here. It will be seen that the practicability of transmission to considerable distances depends upon the proportion of energy delivered to that generated, that is to the waste of energy in the acts of transmission and conversion, and as to this, there are two considerations: (1) the effects with *large currents*; (2) the results with *high E M F*. These subjects have been considered in previous chapters; here it may be said that the question really stands just where it was in 1878, when the subject first received serious attention. Sir C. Siemens then suggested the delivery of electricity generated by a waterfall 30 miles distant, and the conditions of conductor required. The following summary of my examination of the proposal (see p. 257) will show that the transmission by aid of large currents is very unpromising.

> "It appears then that having a free gift from nature in a waterfall 30 miles away, to utilize it as 1000 horse-power we must provide
>
> "(1) Dynamic converters capable of developing 1000 horse-power.
>
> "(2) 1900 tons of best copper rod, properly insulated.
>
> "(3) A dynamo-electric apparatus capable of generating a current representing at starting, 2000 horse-power.
>
> "(4) Means of cooling that machine and dissipating rapidly a constant energy equal to 758 horse-power.
>
> "It becomes a very serious question whether it would not be desirable to look that gift-horse-power in the mouth. Without going into figures, it really seems that it would be cheaper to buy steam or gas engines, and pay for coal to do the work on the spot.
>
> "That is a question that might receive different answers in the mountains of Chili, and where coal is to be obtained at even the most extreme English prices."

926. A little later, Messrs. Houston and Thomson in America, stated and proved (mathematically) that it is possible to convey *the total power of Niagara a distance of* 500 *miles or more* by a copper cable not exceeding one half-inch in diameter. This is the exaggerated extreme of the second condition of transmission, the use of a small current under very high E M F, § 502. This system has been supported by the most energetic worker in this field, M. Deprez. But so far it appears that the best result he has yet realized is the delivery of about 33 per cent. of the original energy, at a short distance.

927. It has been proposed to transmit energy under extremely high E M F across the open country, and to reduce this by means of secondary batteries to the limit which might be safe in practice; thus 1000 cells in series can be charged by an

E M F of say 2500 volts, while each cell would give up an equal current at an E M F of 2 volts, or as many could be combined as is required: but more knowledge is necessary as to the practical transmission of electric current before any actual results are likely to be attained.

928. Great expectations as to the capacity of transmission are sometimes expressed, and while Jacobi's calculation of maximum work is $\frac{e}{E} = \frac{w}{W} = \cdot 5$ it is stated by some that $\frac{e}{E} = \frac{w}{W} =$ nearly 1 may be looked for, and that 80 per cent. of the original energy may be transmitted.

The true possibility may be easily derived from commonsense calculations, such as have been presented, §§ 920–924; it can never be higher than the *product* of the nett efficiency of the *generator and the converter, less the proportion lost in the conductor.* It is scarcely possible that the nett efficiencies will exceed 80 per cent., and 80 × 80 = 64, so that if we allow 10 for conductor and leakage, we come pretty near the 50 per cent. of Jacobi's law. No machines at present in existence can realize this result.

929. It is more likely that electric motors may effect a revolution in factory working, as their convenience and easy control, together with the fact that they can be made very small, will tend to their employment in doing work direct instead of power being transmitted from an engine by shafts and gearing, especially where a rapid revolution is required.

930. In all cases they ought to be worked on the multiple arc system, so that there shall be no mutual interference, but all being supplied and adapted to a constant E M F, each will close its own circuit and call forth the required current from the generator, as described § 900.

931. ELECTRO-MAGNETS.—These must be considered as consisting of distinct elements or parts, each having its own particular functions or laws to be examined apart from the others, while the sum of the effects is due to the combination of these laws for the utmost mutual action. These constituents are (1) the iron; (2) the wire; (3) the current.

The iron portion is divisible into (1) the *core*, the part upon which the wire is wound, which in a straight bar is the whole of what is usually called the "magnet": in a horseshoe, this is divided into two parts called the *arms* of the magnet; (2) the *base* or piece connecting the two arms; (3) the *armature*, which is truly a part of the magnet, though not usually considered as such: it is in fact the agent in, and by which the magnetic force is manifested.

932. Electro-magnets may often be made on the horseshoe type, but with a coil fitted upon only one arm: in such cases, it is often desirable to utilize the magnetism induced in the separate arm by hinging the armature upon it; of course the same may be done in horseshoes with two coils.

A single bar magnet may be similarly utilized with projecting pole pieces on its ends; the armature would then play parallel with the core, either from a separate support as usual, or hinged upon one of the ends: in this manner, it is influenced not only by the polar attractions of the cores, but it is also in the external lines of the coil which magnetize itself also in the opposite direction to the core. In this case, the best construction would be to screw iron pole-pieces on the ends of the bar, extending upwards over one-third of the circumference, and to form the armature as part of a cylinder of thin iron, which when attracted would come close down upon the coils.

933. The essential feature of magnetism is *equal opposite dualism:* in every magnet there are equal and opposite forces which we call north and south polarities, because related to the earth's poles. Although scientific writers speak of "a pole" and describe its actions very fully, no such single pole ever exists, but the two opposite poles are always connected together. But it by no means follows that the two ends of a bar, though opposite poles, are poles of equal strength, because the so-called poles are only centres of action for fields set up at them, and these fields may be more or less concentrated.

934. The *strength of a pole* is measured by the field it sets up; by its action upon another magnet, § 135. It is entirely different from the lifting power, § 937, which is the usual idea formed of it by ordinary people.

935. A straight core equally covered with wire throughout its length is equally magnetized throughout, and its opposite ends will be equal poles, and both would lift the same weight. But if the wire is concentrated at one end, the core is no longer equally magnetized; its neutral point will be brought nearer to the wired end instead of at the middle: a strong pole and dense field will be produced at one end, and a weaker pole and more diffused field at the other end: the two ends will no longer hold the same weight, because the same number of lines of force will no longer enter it.

936. If a helix, say 1 inch in length, has a core 1 inch long, under such conditions that either end will lift 1 ounce, iron added beyond one end, or in fact lengthening the core, will increase the lifting power, both of the end nearest the wire, for the reason just given, and also the total power of both ends,

because the *magnetic capacity* of the system is increased, and this increased power will extend to a threefold length.

937. A horseshoe magnet is simply a bar magnet turned up so as to bring its ends into the same plane: the *strength of its poles* is in no way altered by this, but *their lifting power* is greatly increased. The reason is that the armature now constitutes a closed circuit in a substance of high capacity: when the two poles of a bar magnet are loaded, the armatures are mere polar extensions, and the lines of force of the magnet have to close themselves through the air, and only part of them will pass through the armatures instead of from the surface of the magnet. The same thing occurs if the two arms of a horseshoe are separately loaded: but when the armature crosses the poles it concentrates all the force of the magnet, and therefore may carry three or four times the weight the two poles could carry separately.

The whole of the lines of force are not confined to the pole, but cross the whole space between the arms, in quantities proportioned to the forces existing at each part of the bar. See § 911. (1).

The intensity of the field, and the lifting power, are greater the nearer the poles are brought together, as explained § 123, while the distance at which power can be exerted is lessened.

938. The *best proportions* for maximum work, are equal lengths of the four parts of the iron: the base to be somewhat heavier than the arms, and the armature to be of equal weight, but spread out in thinner metal to receive the lines of force over large surface. When the armature is intended to vibrate rapidly or more quickly it must be made lighter, and shorter.

939. The *cores* or arms carrying the wire, should have each a length of six diameters (twelve diameters for bar magnets). Cores vary in magnetic strength in the ratio of the *square roots of their diameters*, and also as the *square roots of their lengths*, and the sixfold length is the most effective combination of these. Lengthening the core lengthens the field, and also increases residual magnetism, therefore short cores should be used for quick working.

940. *Hollow cores* are as effective as solid metal, provided the shell is sufficient to absorb the magnetic action of the current, for which one-quarter the diameter is effective: but the ends must be closed with an iron plug of at least equal thickness. The best construction is to bore out the core to the required dimensions, and then slit it lengthwise down one side to

prevent the formation of induced or Foucault currents when the magnetic state changes.

941. The *helix* should be of the same thickness as the core, making the total diameter threefold: this, combined with the sixfold length of core, gives the greatest magnetic effect for a given length of wire. Within practical limits, each *spire* or turn of wire, whether close to or distant from the core, has equal action; but one turn of outside wire would make two of inside, while lengthening the core to gain these turns increases the polar distance and diminishes the number of turns at each section.

The wire is best distributed equally over the arms: but for great effect at very short distances, or for great holding power, the wire may be concentrated near the ends.

942. The *magnetic strength* is proportional *to the current* passing, and to the *number of turns* of wire, which is commonly expressed as "varying as C *t*." It is simpler to combine these in one conception and say it varies "as the *current*-turns," or as the "ampère-turns," referred to § 901, to which a few experiments would give a definite value.

Thus the same magnetic effect may be obtained from a few turns of wire and large current, or a small current and many turns, so long as the product of current and number of turns amounts to the same in "ampère-turns."

This is a consequence of the fact that the same energy is conveyed by the wire. With a given weight of metal the resistance is as the square of the length, i. e. as the number of turns it can make. Current is inversely as this number; therefore if we have 1 ampère in 100 turns of 1 ohm R, the energy by $C^2 \times R = 1$ joulad, then 1000 turns would have 100 R, and the current being ·1 we have $\cdot 1^2 \times 100 = 1$ joulad as before.

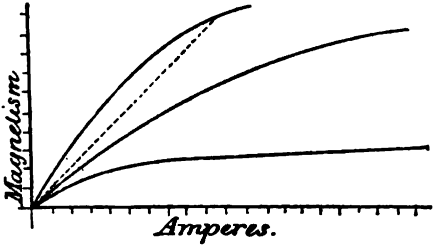
943. To equally magnetize different sized cores, the "ampère-turns" must be in the proportion of the square root of the cube of the diameters.

944. This relation of ampère-turns to magnetic strength holds good only during the lower range of magnetic increase. If it were expressed in a diagram in which the horizontal line measured current in a given helix, or ampère-turns, and the vertical line represented magnetic strength, the resulting line would be a straight one rising at the angle of 45° if equal lengths were taken for the two data. But instead of this, the action is a steadily weakening one, and the line lowers down to the horizontal direction, when additional current causes no further increase of magnetism. Fig. 111 shows such curves

for steel, and various qualities of wrought and cast iron, as to both saturation and capacity.

945. Fig. 111 shows that the *limit of saturation* (§ 138) varies for each quality for iron, and that each quality has its own *capacity*, § 137, that is, the same current will produce different magnetism with cores of different iron, while one quality will reach its limit of capacity earlier than others: thus soft iron has eight times the capacity of hard steel, while cast iron is intermediate. This is why soft iron electro-magnets are better than permanent magnets for dynamo machines.

FIG. 111.



946. *Steel* has two limits of saturation: (1) as with iron, the point at which no increase is possible; (2) a much lower limit, the permanent strength retained, which may be only one-fifth of the first. This is about the strength corresponding to equal action per ampère-turn, and the range at which dynamo-machines do best work. It is evidently bad economy to press the magnetism to the higher limit, because the resulting effect of increased current is small, while the cost of increasing current is as the square of the current, besides the extra waste in increased resistance due to the heat generated.

947. Every kind of iron has therefore its *specific capacity*, that is to say, unit volume or weight can only be made to develop, under any circumstances, a definite "magnetic strength," or hold up a limited weight.

Joule found the utmost effect he could obtain was to hold up 200 pounds per square inch of core, which is equivalent to a force of 13,800,000 dynes per square centimetre. See also § 137.

948. *Size*, which really means *diameter of core*, is the first point to be considered in arranging an electro-magnet, and this will be affected by three considerations at least: (1) the amount

of mechanical work required to be done; (2) the resistance to be taken into account, such as the distance at which the work is to be done; (3) the E M F at disposal.

949. Every action performed by an electro-magnet means a definite amount of energy expended in that action; be it comparable to a horse-power or to the movement of the wheels of a watch, it is to be realized in foot-pounds, and the magnet must be capable of developing a pull capable of lifting the corresponding weight at the extreme distance of its armature. Therefore knowing the limit of capacity of iron, § 947, the size is determinable by the allowance to be made for the quality and conditions in each case.

950. *The current transmitted* must convey the corresponding energy: that is to say, the joulads of energy supplied to the coil, and measured, § 390, by E × C, must be equal to two quantities: (1) $C^2 \times R$, the expenditure in the wire of the coil itself, as inevitable loss; (2) the mechanical energy of the work, which (§ 454) acts like a further resistance.

951. WIRE REQUIRED.—Various formulæ are given to determine the size and quantity of wire necessary, but for the sake of general readers I will deal with this subject physically. The *size of the core* being determined by § 949, the *size of the helix* follows from § 941, and the *gauge of wire* to be used then depends upon the resistance adapted to the conditions, and varies with the nature of the work.

The *resistance* of the electro-magnet should be equal to that of the whole of the rest of the circuit, for maximum strength.

For *quick action*, as in a vibrating armature or a relay, the resistance is made much lower to prevent the counteracting influence of the extra currents, and because the magnet cannot approach saturation. Also in such cases, shorter cores and thicker coils may be used.

952. A helix is simply a *space* measurable in cubic inches, or in the case of circular coils in cylindrical inches.

The *area* is measured, and in circles is as the square of the extreme diameter, less the square of the inner diameter, and multiplied by the length, gives the *capacity* in the measure desired, as in the case of wires, § 468: in fact we may regard the helix for the moment as a bar of copper of which we obtain the weight by multiplying by

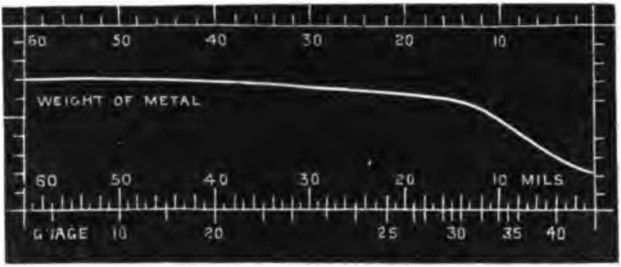
per cubic inch	2247	grains,	Log	3·3516031
„ cylind. „	1765	„	„	3·2467447

953. From this a deduction has to be made for space between the wires and for the insulating material, which will vary with

each make. The best plan to ascertain the actual ratio is to make a mandril with recess sunk in it, of 1, 2, or 3 inches length for different sized wires; wind this with one layer of any wire and count exactly the number of turns contained. The diameter of the *bare wire* measured or calculated, § 474, will give the number of turns it would give, and the ratio of these numbers of turns will represent the space occupied by the covering.

Silk covering is more regular than any other, and I have obtained the curve of Fig. 112, from a number of experiments, as an approximation to the ratio of the weight actually contained in a coil to that of the solid metal, § 952, which of course is less as the size of wire decreases: the height from the lower line to the curve in parts of an inch will give a ratio by which to multiply the solid weight of § 952, to ascertain the actual *weight of metal in the coil.*

Fig. 112.



954. Having the resistance required to be given, § 951, and the weight of metal at disposal, which is the weight of the wire giving the desired resistance, a rule-of-three sum gives weight is to 7000 grains as R is to ohms per pound, and a reference to the Table p. 294 will show the suitable size. Or this may be calculated from the constants in § 475.

$$\frac{3{,}416{,}825}{\text{ohms per lb.}} = \left\{\begin{array}{l}\text{square of area in mils}\\ \text{of the required wire.}\end{array}\right.$$

955. Noad gives the following generalizing formula:

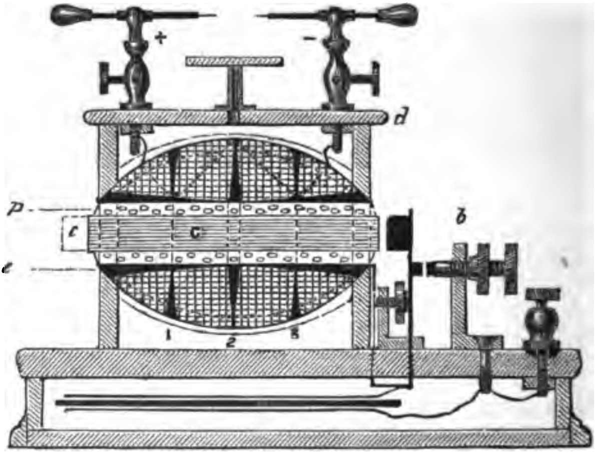
Let M = the magnetic force of the electro-magnet.
n = the number of convolutions.
d = diameter of the core.
C = the current passing.
c = a constant dependent on quality of the iron.

Then $M = c\,n\,C\sqrt{d}.$

956. **Induction Coils.**—These are an application of the principles studied §§ 802–820. They consist of distinct parts, the function of which should be understood. (1) The iron core. (2) The primary wire which conveys current from the battery. (3) The break which interrupts the current. (4) The secondary wire in which the induced current is set up. (5) The insulation. (6) The condenser.

Between all these parts there is a due proportion, and Fig. 113 is drawn to a scale intended to exhibit that proportionate relation for the best construction: it represents a coil 1 foot long in the core, and $1\frac{1}{8}$ inch diameter. The proportions are related to the laws of electro-magnets, § 938, but modified by the circumstance that the core cannot be saturated, and is only acted on for a fraction of a second: therefore it should not be so long as a real magnet; on the other hand, for very large coils, the length is advantageously increased so as to reduce the distance of the secondary. The ellipse shows the most advantageous form in which the wires can be arranged, to occupy the most effective portion of the space marked in thick lines from the points *a b*, in Fig. 85, p. 468, and the following explanation will assist in the making of a coil to the best advantage.

Fig. 113.



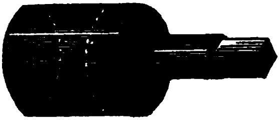
957. *The Core.*—This acts purely as an electro-magnet, and should be made of the purest and softest iron, so that it may magnetize and demagnetize as rapidly and completely as

possible. It must not be capable of setting up an induced current within itself, therefore its own metal must not form a circuit which would act as does the brass covering tube described § 976. It is composed, therefore, of wires of the best quality of No. 18 to 22 gauge, cut in lengths in excess of the intended coil, so as to project at both ends, as shown in dotted lines at one end *c*: they should be made up into a truly round form, which is best done in a metal cylinder of proper size, split from end to end, and bound with wire or cord while the wires are packed: it should then be slid off gradually while a strong wire is wound tightly from end to end of the bundle: this should then be placed in a charcoal fire, made red hot for some time, and allowed to cool as the fire goes out—not by removal. The binding wire should be gradually unwound, and replaced by tape covered by strips of stout paper pasted on to form a cylinder, which when dry, should be warmed and soaked in melted paraffin.

Another plan is to use a mandril of hard wood slightly tapering; form the paper cylinder on this, make the coil complete as follows, and insert the core afterwards; this latter plan is the easiest, but the core is not so perfect, and space is apt to be lost between the core and the primary, which is disadvantageous, unless it is desired to have a removable core for purposes of experiment; then it and the primary may be made to slide in the tube on which the secondary is wound.

Fig. 114 represents a cap of metal to be fitted on to each end of the core or to the mandril, to work in a slot in an upright frame so that a handle can be slipped on either end to wind up the coils of wire. This could be done in a lathe, but is far better done by hand in a frame for the purpose.

FIG. 114.



When the coil is completed, the caps (which may be best secured by shellac cement) are removed, the end of the core at *b* is to be cut off and filed to a perfectly smooth face: the end *c* projecting beyond the calculated length of the core, and the armature at the other end will both add to the inductive actions, as in § 935, by the increased magnetic capacity.

958. *The Primary.*—This should be silk-covered, because the magnetism induced in the core depends upon the current and the *number* of turns of wire, and this number will be greater, the less room the insulation takes up; for this reason, and as there is little tendency to escape, the wire should not be coated

with paraffin, &c.: it should be of the softest quality and the highest conductivity possible. The proper size is of the utmost importance: it must be selected with an eye to the battery power intended to be used so as to develop the greatest current. It is wise to err on the side of using wires *too small* rather than the reverse, because that error partly compensates itself by the greater number of turns, and may be corrected in working by using an extra cell or two. No. 14 would suit a coil a foot long to work with low battery power; for smaller coils No. 18 and even 20. It should be in one length, in case of any accident occurring at a join, and also to avoid irregularity of form which is apt to be caused by a joint. The question as to the advantage of two or three layers is of the same order as that of size; it is a matter of resistance, current, and space occupied: the balance is in favour of two layers. This also brings the two ends to one extremity; if three are preferred, the end of the wire must be brought out and carried back under the stand in mounting. Place the core in the frame with the *b* end to the left, as the wire commences there; tie the wire firmly to it with a sufficient length for connection, and wind up as firmly and closely as possible, beginning at the left hand, and turning the handle upwards to form a right-handed helix. When the layer is completed, fill up the furrow between the wire with a soft cotton cord, or stout knitting cotton, then bind over firmly with a strip of dry silk or silk binding (such as the drapers sell as flannel binding), to prevent any accidental contact by chafe of the wires. Now continue winding on the second layer, and secure it in the same manner. It will be wise now to test the resistance of the wire, which should be slightly greater than before winding: if it is less, there is contact somewhere, which must be remedied by unwinding. The core and primary should now be warmed and well soaked with melted paraffin.

959. *Insulating Tube.*—The core and primary are now to be inclosed in a tube as shown by *e*, Fig. 113, which requires to be thicker at the ends than at the middle, as drawn, because the great risk is a discharge by sparks to the primary, or core, which offer a good circuit. An ebonite tube is usually recommended, but it is costly and difficult to fit exactly to the primary without waste of space. Such a tube can advantageously be built out of the *thinnest sheet ebonite.* Measure the proper size with a piece of paper cut to fit tight; cut out a piece of the ebonite, which is best done with a sharp point, or a tenon-saw drawn over the surface; hold it before a fire till it softens, and bend it over the coil, binding it down with a tape till cold;

then secure the joint with shellac, and add a second cylinder, breaking joint at the opposite side: in a large coil several such layers should be used. Three disks of the thin ebonite are to be cut, with central holes to suit the position, as shown, and slipped upon the cylinder, which is then thickened up at the ends by shorter cylinders, as shown. When dry these may be turned down to a regular curve, if desired, or the disks being set in position, a strip of paraffined paper may be wound on to the desired thickness, as directed in the winding of the secondary. In disks 1 and 3 there are to be holes through which a length of the secondary wire is passed, as shown. In small coils a single disk will suffice; in larger ones others are to be added so as to leave no space wider than 2 to 3 inches, but so as to keep an even number of spaces. The disks should be thickened alternately at the middle and edges, so that the thin part is where the wire passes from one compartment to the next, that is to say, where the difference of tension is least between the neighbouring portions of wire, this obeying the law of tensions, and corresponding to the actual length of wire intervening between such neighbouring parts. There are two ways of thickening disks: another disk of sheet ebonite may be cut of the proper size and rasped away at one edge, and cemented with shellac on each side of the principal disk; cr disks of paraffined paper may be cut and added at intervals as the wire is wound on, which is readily done by cutting a slit in each so as to slip it on. The first plan is preferable when the thickness is in the centre.

The two end-pieces may be made of ebonite, but well-baked mahogany saturated with paraffin will answer. The inner faces may have a recess cut in them to contain a circle of thick sheet ebonite where in contact with the wires, and if desired, a casing of thin ornamental wood can be used to cover the real ends. In most coils these ends are circular, with a flat face at the lower edge; but in Fig. 113 they are rectangular, in order to carry the terminals and discharger. Whichever plan is preferred, they are now to be fixed firmly upon the insulating tube so as to inclose within them part of the primary, as shown, forming a complete reel. The insulating tube should be carried to the end of the core (instead of being cut off to the ellipse, as shown in the figure), so that the ends may be fixed securely upon it.

960. *The secondary wire* is to be laid on with its turns parallel to those of the primary, and there should be as many turns got into the space as consists with the other essential conditions. The size of wire depends upon the object aimed at. A full bushy spark depends on *quantity*, and this again depends entirely

on the size of the wire. Length of spark depends on *tension*, and this upon the number of turns, and the size of wire will range between Nos. 35 and 40. The coil is to be arranged in the winding stand as before, with the *b* end to the left, or in the reverse position to that of Fig. 113. Fix pieces of wood or cork in all the spaces, except the end 3 *b*, to support the disks; the end of the wire is to be passed through a hole in disk 3, and secured in the space 2, 3 for joining to the wire which is to fill that space, and then wound in the space 3 *b* so as to form a helix corresponding to that of the primary, with the precautions as to insulation described § 961, filling up to the elliptic outline, and leaving the end out, for connection to the terminal. Next fill up the space 1–2 in the same way. Now *turn the reel end for end* in the frame, bringing it as it is in Fig. 113; and fill up the other two spaces, joining the wire to the ends left in the spaces for that purpose; then the spires will all be in the same direction and be a continuous helix, when the two ends at partition 2 are soldered together.

The object of this construction is to concentrate the stresses at the two ends of the coil, where perfect insulation is most easily effected, and to secure the most perfect insulation where it is most required. In the common, because easy, construction with the secondary wound backwards and forwards from end to end, as in Fig. 116, it is obvious that a great length of wire intervenes between the proximate ends of two separate layers, and there is great risk of a spark breaking through the insulation.

961. *Insulation of Secondary.*—The wire itself should be silk-covered; it should be well baked, and laid on while quite dry. It is better for being paraffined, if this is so done as not to enlarge the size, § 978 (3). Between each layer an insulating film is spread, which is usually made of several thicknesses of guttapercha tissue, but it is doubtful whether good paper paraffined, such as is used for the condenser, is not better. The best mode of applying either is to cut it in long slips half an inch wide, fix the end over the end of wire, and wind spirally, so that the strip overlaps half its width. On reaching the end or partition, great care is taken that the space is to be perfectly filled, which is easily done by forcing in a little softened paraffin; the strip should then be folded back on itself close to the wall of the space, again wound spirally back half-way up the space and returned to the end, where it can be left to support the next layer of wire: by this means there are only two thicknesses interposed where little insulation is needed, and four where it is most required. In long spaces or undivided coils, the strip

should be returned two-thirds of the length, and again for one-third, so as to have six thicknesses at the dangerous ends. If paraffined paper is used, the final process will make all secure, but if guttapercha is employed, it will be an improvement to paint round the ends at each layer with shellac cement. Some paint the whole wire thus when laid, but this renders it next to impossible ever to remove the wire if desired. Guttapercha dissolved in benzole or in oil may be used instead of shellac.

When the coil is completed, similar external insulation should be employed, filling up the outer dotted line, Fig. 113. This should be of an air-proof nature, such as paraffined paper or solid guttapercha, otherwise the guttapercha sheet is apt to be destroyed by the action of the air. If paraffin insulation is used, the coil should be slowly warmed for some hours, and then saturated with melted paraffin before applying this external covering.

962. The *continuity of the wire* should be carefully watched throughout, as described § 978 (7), or at least tested as each layer is completed, lest any break should occur unnoticed. It is also a great advantage to test the growing inductive action as the coil progresses, which is one reason also for building it on the core itself. At the earlier stages this may be tested by a suitable galvanometer, connecting up a single Daniell cell to the primary, with a hand contact key interposed, and observing the deflection produced on making and breaking contact: of course, the whole length of wire to be used for the coil must be connected to the secondary from the first, or at least it must be made up to one uniform resistance, so as to observe the increasing electromotive force generated. When the coil has so far progressed as to give sparks, a discharger may be used, and the break key should have the condenser attached. The increasing spark can be thus watched, and any accidental failure of insulation at once detected before it is covered up. The construction of a large coil is a matter of so much labour that these precautions are of great consequence.

963. *The Break.*—The construction of this is simple, but involves important principles. Its objects are (1) to close the battery circuit fully, with as little resistance as possible. This requires a good contact surface at the platinum points and a strong pressure of the spring. (2) To maintain the contact till the core is fully magnetized. This requires the resistance of the spring to be just sufficient, so as not to allow the armature to be moved until the full magnetism is approached: for this reason it is desirable to place the point, as shown, at some distance down the spring, which then assumes a curve before

actually destroying contact. To assist this the spring may be of taper form, thinning away towards the upper end. (3) The iron armature must be of the best soft iron and as massive as the core itself; it in fact acts as a prolongation of the core, and assists the inductive actions.

The construction is simple, as shown *b*, Fig. 113. The spring is secured to a brass bracket, which carries also a set-screw, by which the distance between armature and core and the resistance of the spring are adjusted. A similar but higher bracket carries a screw pointed with platinum, and provided with a loose set-nut to prevent its shifting with the vibrations. The platinum should be soldered in position, but care must be taken that no solder runs over it. A hole should be drilled in the point of the screw, and tinned by means of a pointed wire, and the platinum wire entered firmly in. The piece on the spring may be a piece of thick wire, in which case a hole should be drilled in the spring, in which a reduced end of the platinum may be entered, riveted up, and touched with solder on the back. A piece of stout sheet platinum may be used, in which case the spot it is to occupy should be tinned, the platinum placed, and the iron carefully applied round the edges. Platinum requires to be moistened with flux to enable solder to take readily.

For some experimental purposes a break worked by hand or mechanism is useful, and consists of a spring pressing on a ratchet-wheel revolved at a fixed rate. This may be interposed between the coil and battery, the ordinary break being screwed tightly up.

964. *Mercury Break.*—The mere contact of the point against the spring makes imperfect circuit, so that for large coils a better contact is necessary, which is obtained by using a wire dipping in and out of mercury. The motion may be obtained in several ways: (1) a copper wire can be attached to the top of the vibrating spring of the usual break, Fig. 113, and bent over so as to dip into a vessel of mercury; (2) an iron rod may be fixed on the top of a wooden pillar: a spiral of copper wire of the same gauge as the primary wire is wound loosely around, so as not to touch the iron, and to extend to twice its length: the upper part of the spiral is connected to the circuit, while the lower end is bent out and made to dip into the mercury cup. The passing current magnetizes the iron and contracts the spiral so as to lift the end of the wire out of the mercury.

The mercury cup should have a copper rod in its bottom, by a screw on which its height can be adjusted: the mercury may be rendered less mobile by having silver dissolved in it, and it should be covered with alcohol, or with paraffin oil; the end of the wire should have a stout platinum wire fixed to it, and the cup should have a cover with a hole in which the wire can play freely. Such a break may be made independent of the coil current by being worked from an independent cell, or mechanically, in which case two mercury cups may be used, with a bridge of wire moved by the apparatus and making actual break in only one of the cups.

The mercury itself can be made to break the circuit if a platinum wire serving as + conductor just touches it, and the mercury is covered with water containing a little acid: action occurs similar to that which actuates Lippmann's electrometer, a film of gas forms and the mercury leaves the point, returning again immediately to repeat the process.

965. *The Condenser* is made as described § 69; but for small coils, good paper well dried will answer. The area of foil it should contain depends upon the degree of battery power to be used, increasing with this: it appears that if the condenser capacity is too great, the spark is reduced: possibly by the action referred to § 95, which may lower the magnetism of the core by taking up a charge in the condenser. The best mode of ascertaining the proper size adapted to a coil is to arrange it as described for making, and lead temporary wires to it from the coil, allowing this to work at intervals, increasing the battery power gradually to the utmost likely to be used, and adding sheet after sheet of the foil, as it is observed to produce beneficial effects.

The two faces are connected, as shown Fig. 113, to the spring and screw of the break. Its function is to absorb the "extra current" of the primary, as is shown by the reduction of the spark, which would otherwise destroy the platinum. This enables the core to be quickly demagnetized, and the charge reinforces the battery current at the next close of the circuit.

966. *Simple Construction.*—Very effective coils may be made by careful work, depending upon well-selected paper, § 69, and paraffin; success depends upon securing absence of moisture by baking at intervals, which is best done in a *water oven*. This can be constructed of a tin cylinder standing in a saucepan of water, and boiled: a little hole in the cover of the cylinder should have a piece of pipe fixed to it, so that by holding a piece of cold glass against its end, the absence of condensed moisture will prove dryness. The core being made in a paper tube as described § 957, the ends should be fitted firmly on it, the primary wound on, and the insulating tube commenced by winding on strips of paper of which the first layer or two may be pasted with fresh flour paste; this is allowed to dry and well

baked: the secondary is to be wound on, with insulating strips of paper as described § 961, the ends of which may be just touched with paste to hold them in place: after baking at intervals, the finished coil should be inclosed with a complete casing of paper strips, and after a final thorough baking be plunged into a vessel of melted paraffin, in which it should boil for some hours and be allowed to cool very slowly. This is best done in a tin cylinder just the size of the coil. It is well to make the coil in this way with thin inner ends, which can be made of paper pasted together and dried and made to the exact size required: the coil, thus complete in itself, can then be mounted in ends of wood or other material in which recesses are turned to receive it. This plan is better than using strips of paper paraffined first, as this is apt to be brittle; but if this is preferred, the wire should first be baked and soaked in paraffin, or run through it as wound on: the paper in this case should be warmed as it is applied, to diminish its stiffness and brittleness.

967. *Disk Coils.*—The subdivision shown in Fig. 113 is sometimes greatly extended, the sections being only an eighth of an inch wide. In this case they should be made in pairs upon the same principles as are explained § 960; they should be made to slide over the primary inclosed in a straight tube, and the increasing thickness obtained at the ends by putting additional material in before the wire. The best process is to make a mandril of the proper size with two metal cheeks of the size of the coil, one being movable: a disk made up of paraffined paper is placed against the fixed cheek, then the cylinder of required thickness, another disk through the inner part of which an end of the wire is passed, then the other cheek is fixed so as to form a narrow reel. The wire, which should be paraffined, is now run on so as to fill this space, when boiling paraffin can be run in, which cooling will make a solid mass.

The movable cheek is then to be taken off, another cylinder and disk added so as to form another reel; the mandril is then reversed, fresh wire joined to the end left on at first, and then run on as before. This pair of sections then has two ends on the outside, and can be placed on the primary, to be followed by others similarly constructed, and when complete, the outer ends of the wires are joined together in one continuous circuit, and the whole warmed and treated with paraffin, as in § 966. It will be seen that on this plan the disks replace the insulation between the layers, because in these there is comparatively little difference of potential.

968. DIMENSIONS OF COILS.—It is not possible to give exact

figures to attain definite results, because so much depends on the care expended in the making; as a rule, 1 lb. of wire of No. 36 size should give 1 inch of spark; but beyond 18 inches in length, large coils rarely come up to this ratio. The following figures may be useful, they are taken from records of coils actually made.

Spark.	Core.		Primary.		Secondary.		
inches.	length.	diam.	gauge.	layers.	gauge	lb.	oz.
¼	4	·5	20	4	36	0	3
..	3	·75	20	3	40	0	3
½	5	·7	18	2	36	0	8
1	6	1·	16	2	40	1	0
..	9	·75	16	3	36	1	0
2	9	·75	16	2	36	2	0
3	12	1·	16	2	38	3	0
3½	9	·75	16	2	36	3	3
6	18	1·5	13	3	36	5	10

The two last are disk coils, and the last is that of Mr. Brown, of which fuller particulars will be found, § 975.

The condensers require about twenty sheets of foil for small sizes, rising to fifty or sixty, the size being such as will go under the base of the instrument.

969. THE LAWS OF COILS.—Many people think that force is generated in induction coils; but like all other apparatus they are mere converters of energy, and always return less than is supplied to them. They also indicate clearly the distinction of the two quantities, explained § 572; they appear to actually generate "electricity" or *current* because this is produced in a conductor insulated from any source; the *quantity* of this electricity, or current, depends wholly upon the dimensions and arrangement of the conductor, so proving it to be a mere matter of molecular actions. The *energy* connected to this current is derived directly from the battery in the manner explained, §§ 454–6, which is vividly exhibited with a coil of which the parts are separable.

We can trace the process out very clearly if we assume that the resistance of battery and wire, when the break is screwed down, is 1 ohm, and that the battery can send a current of 4 ampères. Now if the break is so arranged that the circuit is closed for half the time, the current will be reduced to 2 ampères, *not through any increased resistance*, but simply because it passes during only half the time which elapses, and therefore only has half the effect on the galvanometer. Now, if the core is inserted and the secondary wire allowed to generate a current, we may assume that the current in the primary will be reduced to 1 ampère; but *this reduction is due to a new resistance*, which is the work done in core and secondary, representing 1 ohm of resistance. It may appear strange that, while doing work externally, the current is actually reduced and the battery giving out less energy, and it is this point which is to be made clear. At first we have

$$C^2 \times R = 2^2 \times 1 = 4 \text{ joulads.}$$
$$\text{afterwards, } 1^2 \times 2 = 2 \quad ,,$$

But in the first case the *whole* energy is expended in the battery and wire as heat; in the second, *only half* is so expended, the other half passing into the secondary wire as the energy and E M F of the induced current.

970. The effects of a coil depend upon the size of the secondary wire, and its length as mentioned, § 960. *Size* or *thickness* of spark depends on the *thickness* of the wire: *length* of spark depends on *length* of wire; the laws are in fact the same as those of batteries and of the heating of wires. We may regard each turn of wire as an electromotor analogous to a cell of a battery, or to a thermo-electric couple. At each section of the coil equal *electromotive force* is developed in each turn, whether close to the core or at the outside of the coil; but the distinction must be remembered between the electromotive force developed *in* the turn, and the effect produced externally *by* the turn: this will correspond to the actions of a large or small cell of equal force, and, therefore, the inner turns exert more energy than the outer, because their own internal resistance is less in the ratio of the lengths.

971. So also the electromotive force developed *in* the turn is independent of the nature of the metal of the wire, but as the *effect* produced depends on the resistances as well as the electromotive force, wire of high conductivity ought to be used; it will also develop less internal heat. It is, however, a question whether iron may not form an exception to this, because being magnetic it would absorb energy itself, and thus increase the electromotive force it could develop, but it is doubtful whether this would counterbalance the disadvantage of the extra resistance.

972. Coils may be united as cells are, and upon the same laws, and it would seem that more effect would be obtained from the same materials and currents applied in four coils of a

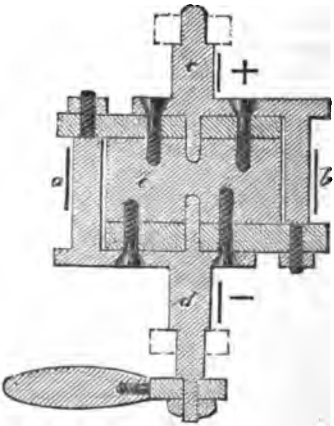
foot long than in one single coil, but coils to be so coupled would require very perfect insulation. They may also be joined in multiple arc, and so increase the quantity, or thickness of spark, but the coils must be similar in construction and force. In these cases each coil should have its own battery, but all the breaks should be screwed down, and a separate single break inserted in a common return wire so as to act on all at once.

973. MOUNTING COILS.—In Fig. 113, *d* is a slab of glass, ebonite, or prepared wood, fixed upon the ends of the reel, forming a frame the sides of which may be advantageously closed with glass, so as to protect the coil from damage by dust and damp; a tube in the middle of *d* carries a rising table of ebonite; and the two pillars + and − connected to the terminals of the secondary, constitute a universal discharger; they are, in fact, an elongated binding-screw, to which wires to any apparatus may be attached. They terminate at the top with a spherical socket, forming a universal joint. The rods, carrying wires, &c., slide in a tube, so that their distance, position, &c., are under perfect control.

In most coils these pillars, or insulated binding-screws, are placed on the stand at the end or the side of the coil, but the arrangement shown is much more convenient for large coils. The two ends of the primary pass down through the stand outside the end of the reel at *b*, the inner is connected to the spring of the break, and by it to the binding-screw, as shown: the outer end goes direct to the other binding-screw.

974. It is, however, better to have a commutator on the stand to reverse or cut off connection with the battery. The best construction for this purpose is shown in full-size section, Fig. 115; *e* is a circular or elliptic block of wood or ebonite, with a cheek on each side projecting beyond opposite ends of the diameter to afford a fastening for the metal portion. This consists of two similar pieces of brass, *c d*, which may be built up of several parts or cast in one, as shown. These form the axis on which the apparatus

FIG. 115.



moves, and each of them being continued up one side and across the end of *e*, forms a path between two springs touching them. The cylinder is supported in two brackets, as shown in dotted lines, and to these brackets are also secured springs + and −, which being connected to the battery binding-screws, bring the current to the commutator. Two other springs *a b* convey the current away, either being made positive according to the direction in which the handle is turned. When this is vertical, the current is cut off altogether. These springs should be fixed to small brackets with stems to pass through the foundation plate of the instrument, and are to be used in place of the principal binding-screws for all connections directed to be made to these.

975. NOTED COILS.—(1) *Rhumkorff* has constructed some, containing about 60 miles of secondary, which with 1 Bunsen cell gave 3¼ inches spark, and 16 inches with 7 cells.

(2) *Ritchie* made one for Gassiot, the core 18 inches, 1¾ diameter; the wire covered with guttapercha $\frac{1}{10}$ thick; the primary, 9 gauge, 150 feet in three layers. The secondary in three cylinders, each 5 inches long, made of guttapercha $\frac{1}{10}$ thick; the wire of the middle one, 32 gauge, 22,500 feet long; the others of 33, each 25,575 feet. There are three condensers, of 50, 100, and 150 feet, capable of combination. With 5 Bunsens, each coil gave a spark of 5 inches; the three gave 12½ inches.

(3) *Siemens and Halske.*—Made with a great number of partitions of sheet ebonite, contained 80 miles of secondary, and gave sparks from 1 to 2 feet in length.

(4) *Yeates'.*—In two compartments; core, 22 inches by 1¼; primary, 12 gauge in 2 layers; secondary, No. 36, in 55 layers, making 55,000 turns, insulated with guttapercha tissue and paraffined paper, 10½ miles in length, and 10½ lb. in weight; condenser, 66 sheets of foil 11 × 29, with paraffined paper. With 5 Grove cells it gave 12¾ inches spark.

(5) *Ladd's.*—Core, 1 foot long, 1·8 inch diameter; primary, 12 gauge, 50 yards in three layers: secondary, 3 miles, No. 35, in layers from end to end, each separated with five or six sheets of guttapercha tissue; condenser, 50 sheets of foil 18 × 8 on varnished paper: gives 5 inches spark with 5 Bunsens. One constructed for Dr. Robinson, with two secondary coils, each 5690 yards, or together, 6 miles 820 yards, is said to give sparks 2·04 inches with one cell; 5·06 with two; 6·45 with three; 7·65 with four; and 8·38 with five cells.

(6) *The Polytechnic.*—Length from end to end, 9 feet 10 inches; diameter, 2 feet; weight, 15 cwt., containing 477 lb. of ebonite. The core, 5 feet long, of No. 16 wire, 4 inches diameter, 123 lb.

The primary, 145 lb. of 13 (·0925) 3770 yards, making 600 turns in strands of 3, 6, and 12 wires; total resistance, 2·2014 ohms.

The secondary, 606 lb., 150 miles long, and resistance 33,560 ohms, on an ebonite tube ½ inch thick and 8 feet long, the coil itself occupying 54 inches in the middle of the tube.

The condenser is in six parts, each containing 125 square feet of foil. The foil gave 12-inch sparks with 5 large Bunsens, and 29 inches with 50 cells. Particulars of experiments may be found in No. 513 of the *Chemical News*, Sept. 24, 1869. This coil did not endure long and is broken up.

(7) *Spottiswoode's.*—This, made by Apps, has two inducing systems, (1) for long thin sparks, core, 44 × 3·5 inches, weighing 67 lb.; primary, 660 yards of ·096 wire, weighing 55 lb., in 6 layers and 1344 turns, with resistance 2·3 ohms. (2) Core, 44 × 3·8 inches, weighing 92 lb. Wire, 504 yards, weighing 84 lb., in 3 layers, each forming a distinct circuit.

The secondary is 280 miles long, with resistance 110,200 ohms. It is in 4 sections, with 200 layers in each, and a total of 341,850 turns.

The condenser is 126 sheets of foil, 18 × 8½ inches, separated by varnished paper ·011 thick. With 5 quart Grove cells a spark of 28 inches is obtained, 35 inches with 10, and 42 with 30 cells.

(8) Mr. J. Brown of Belfast has made a coil on the disk plan, giving very good results. The core, 18 × 1·5 inch of No. 22 charcoal wire, has a primary of ·1 wire, 73 yards in 3 layers, making 460 turns, in a vulcanite tube ¼ inch thick.

The secondary is 5 lb. 5 oz. No. 36, and 7 oz. No. 35, 5½ miles long, with 5310 ohms resistance, wound in 44 disks, each about 3-32nds or ·1 inch thick; those in the middle, 3 inch internal diameter and 5·5 external; at the ends 3·25 and 5. The wire was wound on through melted paraffin and the disks made of four thicknesses of thin unsized paper, and the secondary only occupied 5·5 inches of the middle part of the core.

The condenser is 48 sheets, 9 × 6½, separated by 2 sheets of paraffined paper.

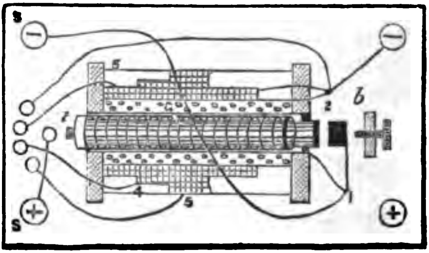
Sparks of 5½ inches were obtained at first, but by covering the secondary with 3-8ths of paraffin, they were increased to 8 inches with 5 Groves.

976. Medical Coils.—These depend on the same principles as induction coils, but they are made to give pulsations of comparatively small force but of larger quantity. For this purpose the "extra" current of the primary itself should be utilized, and stouter secondary wires employed. A great variety of arrangements are employed, vertical and horizontal. Fig. 116

shows the most convenient plan, in which a current in one direction only (that of breaking circuit) is given off: By means of the commutator, which employs different lengths of wire, the energy can be varied, and the sliding tube over the core controls the force of the shock produced, with the greatest nicety. The action of this tube is, practically, to shorten the core as far as it covers it, so far as its inductive reactions are concerned, by enabling the induced current to form in the tube itself instead of in the wire outside it. The following particulars relate to a coil 6 inches long in the core.

On a mandril about an inch diameter, slightly tapering, make a pasteboard tube of three or four thicknesses of brown paper, and form a reel by gluing on this two turned ends of 3 inches diameter, leaving a space of 5 inches between them. There should be a groove on the inner faces of the ends towards the edge which is to be secured on the stand (and which is there slightly flattened) for the wire ends to lie in. Lay on four continuous layers of No. 18 cotton-covered wire, and bring out several inches of the ends, calling the inner end 1, and the outer end 2. To 2, just where it leaves the coil, join a length of No. 22 or 24 wire, which will commence the secondary; when four layers of this are placed, bring out the end, calling it No. 3, and joining to it, as before, a continuation of No. 26 or 28, calling its outer end No. 4; to which, if desired, a further length of finer wire may be added. All the wires may be cotton-covered, and should be soaked with paraffin before or after laying.

FIG. 116.



A brass tube *t* is cut to slide freely within the primary tube, and at one end a thin piece of metal is soldered within it, to serve as a stop; a bundle of soft wires is then packed within the tube, and a ring fitted upon its inner end to abut against that just described, and prevent the tube from being drawn entirely off the core by the handle *t*, fitted to the tube itself at the same end; the other end of the core is then passed through and secured to the farther end of the coil *b*, by wedging and cement, and trimmed off smooth to work the break *b*, which is similar to that described § 963. Fig. 116 explains the connections: + and − are the battery screws; + is connected to the screw of the break, and the inner end of the primary, 1, is connected to the spring, which is also connected to *s* −, one of the secondary binding-screws; the end 2 of the primary is connected to − for the battery circuit, and also to the first stud of the commutator for the secondary circuit. The secondary wire is shown in stages and numbered; it begins at 2, by being soldered to the end of the primary; the ends of the various lengths, 3, 4, 5, are taken to successive studs of the commutator, the central spring of which is connected to *s* +. The commutator takes up either the "extra" current from the primary, or that with the added effect of the lengths of secondary, according to the stud on which the spring is placed. As arranged, that secondary binding-screw will be +, which is on the same side as the primary screw connected to the + pole of the battery: the current taken up is in the same direction as that of the battery, *in the coil*, therefore if the inner end of the wire is so connected as shown, the outer end is of course the + conductor from the coil. The effect of this mode of connection is, that when contact is made, the battery offers a path of much lower resistance than the body; therefore the current induced at making contact does not pass through the body, which, transmitting only the current of breaking circuit, is subjected only to the influence of a current in one direction. This is considered of great importance in some cases, but it is extremely doubtful whether the action of coils is a truly electrical one at all, as to its medical effects: it seems probable that these are principally due to the muscular contractions and releases, to the internal frictions and motions thus produced, and consequent disturbance of congestions, and stimulation of the nerves. Care should be taken to avoid violent shocks or pain, and it is important that the break should work with a soft hum, not with violent jerks. This is why the action of coils is superior to the more jerky shock given by magneto machines.

977. *Small coils* may be made to be carried in the pocket, such as are made by Gaiffe of Paris, and others, worked by one or two chloride of silver cells, § 239, fitted up in ebonite cylinders with caps to screw on, and working by the liquid soaked up in paper between and round the plates. In these the connections are made by studs of metal pressing against springs fixed on the inside of the outer case; the vibrating

spring of the coil is similarly attached to the case, and the coil itself is loose and makes its connections by the act of placing in the case; those of the conductors are made by split wires, at the end of the flexible wire cords, which are pushed into metal tubes let into the case, and the graduating tube works through a hole in the side. Such coils may be made even 2 inches in length, with primary of 22 wire and secondary of 30, all silk-covered and paraffined; the vibrating spring being made of thin watch-spring.

978. Management of Wires.—This is of great importance, especially in constructing coils. The greatest care is requisite, for there is little satisfaction in spending much time and labour in winding up a great length of wire, and then discovering that there is a break in it at some unknown point. The following precautions, though very troublesome, will well repay the trouble.

(1) Test each reel of wire for continuity: sellers rarely furnish reels in which the wire is continuous from one end to the other. The test requires a delicate astatic galvanometer and a cell to send current through the wire.

(2) If not continuous, wind upon a fresh reel, passing the wire through the fingers and carefully watching it. It is best to use a tin reel for this purpose, or, at all events, to use a metallic axis against which a spring can be placed, soldering the beginning of the wire to the reel. By this means a permanent test can be kept up, and measurement of resistance, length, &c., can be made at any time.

(3) It is desirable in many cases to paraffin the wire. It should be first well baked till all moisture is driven off, and while hot should be dipped into the melted paraffin, or this may be poured over it. For fine wires the paraffin may be thinned with turpentine, or benzoline, which will prevent the wire from being much enlarged. It is desirable to warm the reel of wire when it is about to be used so as to soften the material.

(4) The paraffin may be applied while winding, by passing it under a roller at the bottom of a tin vessel containing the paraffin kept melted, and through a hole in a cork as it leaves the vessel to remove excess; the wire ought to be well dried just beforehand.

(5) The resistance of the wires should be taken, and noted; then by measuring that of a known length, the length of wire used for any purpose may be nearly ascertained.

(6) In winding up coils, &c., it is very desirable to ascertain the exact number of turns the wire makes: this may be done

with a revolution counter, easily made up from such wheels as are used in gas-meter indices. This may be actuated either by an attachment direct to the end of the axis of revolution, or by an electro-magnet actuated at each revolution by an ordinary circuit-closer. The best plan is to have a worm cut on the winding axis, to work in a wheel with 100 teeth, then the rest of the work can be fitted up with wheels as used in meter indices.

(7) With fine wires a constant test for continuity should be maintained. The beginning of the wire of the instrument should be connected to a metallic cylinder on the axis, against which a spring should press, as in (2) above. This spring and that of the wire reel are connected to a galvanometer and a battery: if a commutator is used, the current need not be continuous, but a test current can be sent through at intervals, or on completing each layer. This affords also a check upon the insulation, as any accidental contact will reduce the resistance, which ought to increase continually as the wire is strained by winding.

(8) All joints should be carefully made, stripping the wire, cleaning it, tapering the ends and tinning them; fine wires should then be carefully twisted together and soldered, which is best done by means of a piece of No. 10 copper wire in a handle. If this wire crosses a gas flame, the point beyond (being well tinned) will act as a convenient soldering-iron for very fine work. The joint should be carefully covered without increasing the size of the wire; this may be effected by rubbing the warmed wire with a stick of cement made of guttapercha and resin melted together. Only resin should be used as the flux in soldering wires.

CHAPTER XIII.

ELECTRIC LIGHTING.

979. The study of light involves four distinct considerations: (1) The phenomena of its origin. (2) The mode of its transmission. (3) The nature of its perception. (4) The energy expended in its origin and absorbed in its perception and actions. Although it would be out of place to examine here the whole subject of light, it is necessary to clearly define these points in order to comprehend the production of light by electricity, and especially the economic aspects of this subject.

980. Light is not a *thing* having any existence of its own, it is an action, a motion of vibration. In fact, light as it is commonly conceived, *has no existence at all outside of our perceptions.* The light is in the eye, it is a sensation produced by a rhythmic motion, which other organs perceive in a different form, which we may know by other names.

981. Motion may be irregular and indefinite, or it may be rhythmic; it may be in straight lines, deflected in any direction by obstacles, as radiant energy: or it may, when due to two co-acting forces, be vibratory like that of a pendulum. Undulatory or wave motion is of this latter order, and is rhythmic; that is to say, its vibrations are of equal intervals. Thus a pendulum swings in exactly the same time, whether its swing be merely perceptible, or ranging over nearly the semicircle. But here it must be noted that this applies to the theoretical pendulum, swinging in vacuo without friction; the actual pendulum is influenced by a retarding action which makes each successive motion vary, unless a force lifts it, at each interval, to its starting height, as is done in clocks. This same principle applies to many general laws; they must be accepted as related to theoretical conditions which cannot be actually realized.

982. Such a rhythmic motion we can observe in the simplest form when we throw a stone into a pool of water, and produce a set of circular waves, which are reflected from the edges, and ultimately lost in an apparent confusion, which is really perfect

order, but too manifold for our eyes to distinguish: we can see the waves crossing each other, neutralizing each other as they cross, yet each remaining unaffected; we can see in this, that each molecule of the water, while itself merely rising and sinking in a vertical direction, may be subjected to and transmit many stresses in different directions.

983. *Sound* is such another rhythmic motion of the particles of air and other matter, which becomes what we call sound only in the act of perception; in the intermediate space it is merely a vibrating motion, which another perception translates into a succession of blows, as when we lay our finger on a sounding board. It will be understood therefore, that we can really *see* and *feel* sound, and this will illustrate the meaning of § 980. As there said of *light*, so now we may say of *sound*, that it has no real existence. What really exists is *motion*; it only becomes sound by the perceptive action of our nerves of hearing, and it is the same with the more refined motion which our optic nerves translate as light.

Musical sounds are definite rhythmic motions, and each note of the musical scale means a fixed number of vibrations per second; the strings of a piano are each of such a weight and strain as compel them to make this fixed rate of vibration, which is then transmitted through the air, and felt by our ears. The particles of air, like the particles of water, § 982, can thus take part in many motions, and transmit each unchanged; the quality, or *pitch* of each specific note is related to the number of such swinging motions per second, while the *loudness* depends upon the amplitude, or width of the swing; two things analogous to the length of the pendulum and its consequent period of swing, and to the height to which it may be lifted and fall through.

984. *Sound has a reactive power* also: if we sing a specific note to the wires of a piano, the corresponding wire will take up the motion and reproduce the note; other wires which are *harmonics*, that is vibrate in 2, 3, &c., equal times, will also vibrate, but less powerfully.

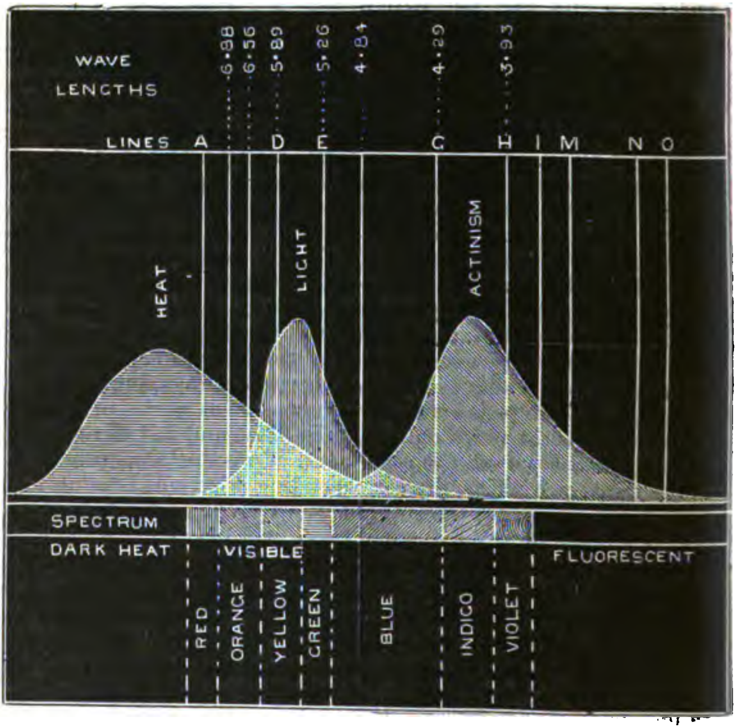
985. *Light is a motion* still more refined; so rapid that it is attributed to a medium more delicate than matter, the ether; though matter takes up and is affected by this motion. But light, as we know it, is not a simple motion, but a combination of an infinite number of distinct wave-motions, uniting together in one grand harmony, like the united sound of an orchestra, which is the blending of a multitude of separate sounds, each of which may be distinguished among the united volume of sound.

986. In light, as in sounds, we can distinguish the individual

rhythm which corresponds to a note in music, and is a definite *tint of colour* in light. This analysis of light is effected by passing a ray of light through a substance which acts differently upon each wave-length, that is to say, upon a triangular piece of glass, or other substance, which spreads it out from a narrow line of mixed light into a coloured band, known as the spectrum, which is simply a series of lines of light, each of a specific wave-length, blending into groups of similar shades to form the seven colours of the rainbow.

987. This spectrum, which is shown in Fig. 117, may be

FIG. 117.



regarded as the analogue of an opening across the front of a piano, showing the row of wires. The white vertical lines show certain exactly measured lines which appear as dark lines in the sun's spectrum, because their light is absent, having been absorbed in passing through gaseous bodies in the sun's atmosphere; the figures represent wave-lengths in ten-millionths of a millimetre, and they are measured by the thickness of the coloured films which produce them, as in soap-bubbles.

988. These dark lines are due to the same action as that of sound, § 984. Every substance in nature is in a motion characteristic of itself. The specific energy, § 516, of each atom is doubtlessly stored in the form of this motion, either vibratory, or revolutionary, which would act as a vibration externally, and each atom has a specific rate of motion, just as each length of pendulum has: this rate is altered in combination but is constant for each physical condition of the substance. Each atom of matter, therefore, when it acts as a producer of light, gives out its specific light, which in the gaseous state is in the form of bright lines; the line D, which is really two lines with an intermediate wave-length, being the specific line of sodium; the atom, therefore, takes up from light its own specific motion, and the sun's light (as any other), in passing through the cooler gaseous atmosphere, is sifted by the different substances it contains, and largely deprived of those particular rays. It is thus we learn what substances are present in the sun.

989. Just as in sound it requires a certain rate of vibration, of above 27 per second to be appreciable by the ear as a note, and as, above about 3520 vibrations, sound again becomes inappreciable (and inaudible at about 24,000), these being the ranges of a seven octave piano, so it is only within a certain limit that the undulations of radiant energy are appreciated as *light* by our organs of sight, which may be said, in fact, to convert this range of radiant energy into light.

990. It will be seen from Fig. 117 that this visible spectrum extends over only *one octave of light*, an octave being a doubled rate of vibration, and it is very remarkable that the wave-lengths of the middle of each of the seven colours hold relations almost, if not truly, identical with those of the musical gamut; but what we are concerned with is that the spectrum of an incandescent solid shows, first, a range of rays which do not act as light, then the graded lights or colours of the spectrum, and, finally, a further range, invisible as light, but producing chemical effects. These are even capable of becoming visible when received upon *fluorescent* substances, such as sulphate of quinine, which, like the harmonic notes in sound, are capable of taking up these vibrations of short wave-length, and giving them out again in waves of greater length, which then affect the eye, as § 1032 shows that the heat-rays may be similarly transformed into light.

991. The three shaded curves of Fig. 117 show the ranges of what used to be considered as distinct forces, heat, light, and actinism. We know now that no such distinction *exists in the rays themselves;* the distinction lies wholly in the *substances which absorb the rays*, and the different effects produced. Thus, the actinic spectrum represents really the rays which were chiefly absorbed by the silver salts first used in photography; it appears, however, that chemical actions generally require rays of short wave-length, while the molecular motion which we call heat is chiefly produced by rays of greater wave-length than those which affect the eye as light.

992. *Physical state* affects the action of radiant energy. Thus, § 988 shows that in the gaseous state, in which, § 593, the relations of matter and energy are most simple, each form of matter will only generate its specific ray motion, and gases radiate very little heat. But all solids can give out rays of all orders, and, in this case, the rays of quick vibration cannot be set up without being accompanied by all the slower waves.

993. Possibly the best conception we can form on this subject will be attained by thinking only of "energy" charged on vibrating molecules; this is really mechanical "work," and therefore we can understand the meaning of the "mechanical equivalent of heat," because heat is the measure of the energy charged upon matter in this state of motion which we call heat. *Temperature* we may regard as the *density of the energy*, and diminished wave-length is the result of, and corresponds to, increasing temperature in the radiant source. But as "light" is a sensation only, there can be no "mechanical equivalent of light," except in the form of the heat equivalent belonging to the rays which produce the sensation, and which also produce the effects of heat.

994. The most beautiful illustration of these principles is to be obtained from the electric current in the experiment first published by Dr. Draper. If we adjust a platinum wire to the slit of a spectroscope (whose lenses and prisms are of rock-salt or quartz crystal), we can build up the spectrum of Fig. 117 by passing a graduated current. As the wire heats, a thermopile, movable along a screen on which the spectrum is directed, will show heat at a point on the extreme left, but none on either side of it: now, as the wire is slowly raised in temperature, as in § 379, heat will extend towards the right, and the degree of it will rise, as the curve shows; but this is not the point at present in view, which is, that this rise of the *quantity* is distinct from the *quality*, the wave-length exhibited by the position in the spectrum scale. When the wire begins to show

red, this colour will appear on the screen *alone*, and so on, as temperature rises, tint after tint will grow out like rungs added to a ladder, till the visible spectrum is completed as the wire approaches the white heat: in like manner the ultra-violet spectrum grows out as the heat is further raised.

995. It is easy to comprehend this, when we recognize that the transmission of current means molecular motion; that as rate of current increases, rapidity of motion increases, and that these motions are propagated as corresponding radiant undulations in surrounding space. It follows, also, that every source of light has its specific quality, depending upon the temperature to which the light-giving body is raised, and the specific properties of that body as to the proportion in which it can generate rays in different parts of the spectrum.

996. DEGREES OF TEMPERATURE.—High temperatures are very difficult of measurement, but it is likely that the spectroscope will give information on them before long, by enabling us to measure the growing heat in particular lines developed from bodies at these temperatures, on which lines Prof. Crova has been working, § 1006. The following table gives the best information at present attainable, from various sources:—

TABLE OF TEMPERATURES IN DEGREES FAHR.

	°
Absolute zero −273° C.	−460
Tin melts	+455
Lead „	620
Zinc „	793
Red just visible ..	977
„ dull	1290
„ cherry, dull ..	1470
„ „ full ..	1650
„ „ clear ..	1830
Silver melts	1832
Cast iron (white) *melts*	1920
Orange, deep	2010
„ clear	2190
Cast-iron (grey) *melts*	2190
Gold melts	2282
White heat	2370

	°
Steel melts	2370
White, bright	2550
„ dazzling ..	2730
Wrought-iron melts ..	2912
Platinum melts	3700
Iridium „ about (?)	11400
Flames in Hottest Part.	
Stearine candle ..	1725
Paraffin lamp	1890
Gas in argand	2100
Spirits of wine ..	2160
Gas in Bunsen ..	2475
(some give 3500)	
Gas in oxygen	2760
Electric arc	8700

997. *Proportion of Energy as Light.*—Two results follow from the conditions of §§ 990–6. Part only of the energy expended in raising temperature appears as light, and the ratio of this part increases as the temperature is raised. Tyndall passed light of different intensities through a solution of iodine in bisulphide of carbon, which, while perfectly opaque, is diather-

manous, or allows heat-rays to pass, while absorbing light-rays entirely. His results are:—

Source.	Absorbed.	Transmitted.	Source.	Absorbed.	Transmitted.
Dark spiral ..	0	100	Gas flame	4	96
Low red „ ..	0	100	White-hot spiral	4·6	95·4
Hydrogen flame	0	100	Electric light (50 cells)	10	90
Oil flame	3	97			

It is estimated by Siemens that in an arc lamp of 3300 candles, one-third of the energy becomes luminous, and that the incandescent lamps utilize about the proportion shown above for the white-hot spiral of platinum.

998. *Gas consumption* teaches the same lesson, which will also be found in the working of incandescent lamps. If we divide the feet of gas burnt by the candle-power of the light, we find that the greater the quantity of gas which can be fairly burnt in a single flame, the lower is the quantity of gas per candle-power. The standard of consumption is a gas which, consumed in a defined Argand burner at the rate of 5 feet per hour, gives 16 candles' light. The same gas burnt in badly proportioned batswing and fishtail burners may only give 10 candles or even less. The rate of 5 feet per 16 candles is ·3125 per candle; but 250 candles can be obtained from a 60 foot burner, which is only ·204 per candle, and even better results are obtained from Siemens' regenerative burner.

999. The reason is, that the area of the flame is lowered and its thickness increased, so that there is less heat radiated off and the temperature of the flame is higher; this, also, is why the cylindrical flame of the Argand, cased in by the hot and non-transmitting glass tube, gives higher efficiency than the exposed flat flame. The most striking illustration of this is the often-patented double burner: if we attach two small burners to flexible tubes, and allow them to burn side by side, we may note the light effect; now if the burners are inclined to each other, so that the flames blend in one, a very great increase of light is perceived. But this increase is a delusion, so far as the double burner is concerned, for it only gives the same result as a well-constructed burner consuming the same gas as these two. The real point is, that the putting that gas into two burners reduces the light it can give.

1000. *Photometry.*—The measurement of light is effected in terms of a standard, or unit light, and is based on the law of the intensity of the action of any light being inversely as the square of its distance. The simplest mode used in testing gas is by the Bunsen photometer, which is a graduated bar, at the two ends of which are the lights to be compared. A screen of white paper, with a greased spot in the middle (or *vice versâ*), is movable on the bar, until the spot is equally visible or undistinguishable on each side; i.e. till the two lights have equal power on it, when their strengths are proportionate to the square of the distances. The bar being graduated in terms of the standard, the strength of the light to be measured is read off the scale at once.

1001. *The legal unit of light power*, in the case of gas, is a spermaceti candle of 6 to the pound, burning at the rate of 120 grains per hour. But the candles vary in quality and in rate of burning. The French standard is the Carcel oil lamp, which equals 9·5 or 9·6 standard candles.

1002. *Sugg's Argand gas-burner* is a better standard for large lights, as it has the property of giving 16 candles' light from gas of all qualities, provided the flame is adjusted to exactly 3 inches in height; of 12 candle gas it requires 6·6 feet per hour to produce this flame, 5 feet of 16 candle, 4 of 20, 3·2 of 25, and 2·7 of 30 candle gas, such as is produced from cannel coal.

1003. Gas lamps of much greater power are required for measuring powerful arc lights, in order to reduce the distance at which they would require to be placed, and these have to be themselves tested. But the measures of these powerful lights are of a very problematical value both on account of the difficulties of the measurement itself, § 1007, and because no arc light in existence remains of uniform strength from moment to moment.

1004. *Electric standards* have been proposed, as a platinum wire of given dimensions, with a fixed current passing: a number of these might be arranged to give a large light, but each wire would require careful adjustment as to current, because no two pieces of platinum are alike; definite alloys of platinum and iridium may yet enable the conditions to be attained. Carbon lamps could not be trusted, because of their varying value by lapse of time, and from the action of even an invisible film of carbon, § 1011.

1005. *Chemical Photometry* may prove valuable, as many reactions, such as those of photography, will give exact results. The combination of equal proportions of perfectly pure hydrogen and chlorine has been utilized in the photometer of Bunsen and Roscoe, but it really gives indications of the ultra-violet rays, rather than of true light, and in fact the actinic curve of Fig. 117 is obtained from this reaction.

Mercuric chloride, dissolved in oxalate of ammonium, is reduced to mercurous chloride by light; but this also is chiefly by the ultra-violet rays, and is variable with the strength of the solution.

Iodide of nitrogen, in water and ammonia, has been very recently employed by M. Antony Guyard, and is said to set free nitrogen in proportion to the light, but under the influence of what rays is not yet stated.

1006. *The best measurement of light* will probably be effected by the comparison, not of the total lights themselves, but of some specific part of the spectrum, such as the D line, which is present in all lights, and represents the middle of the most effective portion. If a chemical reaction of such a line could be found, and conveniently used, it would give a quantitative measure. By passing both lights through similar prisms, and using only the selected rays on the photometer, useful information would be obtained, and this is the process used by Prof. Crova, § 996.

1007. *Powerful lights* can only be very approximately measured, because they cannot be compared direct with the standard candle, on account of the great length of bar required, and because there is an intrinsic difference in colour: even in comparing the candle and gas, with only twentyfold difference in power, and close likeness in colour, two observers will differ, and when the difference becomes one or several thousandfold, this difference is serious.

1008. Absorption of Light.—In § 994, reference is made to rock-salt and quartz. Not only have gases their specific rate of generation and absorption, § 988, but all substances have a specific relation to different rays. Thus we have the distinction of opaque and transparent bodies, and the selective power for colours. But even *transparent* substances take toll upon the passage of radiant energy: the clearest glass takes up a large portion of the long-wave rays, as well as the ultra-violet. Thus we have the use of glass for greenhouses, which prevents the escape of radiant heat, while admitting the sun's rays; also, with a sheet of glass held before the eyes we may safely look into an intensely heated furnace, and examine the actions going on. On the other hand, an opaque substance, like ebonite, permits the free passage of the rays which glass absorbs, see also § 997, and rock-salt and quartz crystals are almost the only substances which are nearly indifferent to the passage of all rays.

1009. *The absorbing power of glass* is of practical importance in lighting, thus

Clear glass absorbs	10 per cent.
White ground	30 " "
Opal	60 " "

Coloured glasses, in addition to the absorption of the glass itself, take up the rays complementary to the colour transmitted, so that if we pass a light through first a blue glass and then a yellow glass scarcely any light at all will remain.

1010. In connection with this subject it should be understood that no change can be made in light once produced except by taking some of the rays away. We may give a tint to an arc light by burning a substance in it, thus a soda salt will give yellowness to the light; but we cannot *give* yellowness to an arc light, once produced, by passing it through anything; we may *take* away the excess of violet and make it appear yellow, but in so doing we reduce the light.

1011. Incandescent electric lights are subject to a special absorbing agent. The carbon wire, especially when overheated, gives off, in some cases, a vapour of carbon which forms a nearly imperceptible dark film upon the inner face of the glass: this thin carbon film has extraordinary absorbent powers; a piece of glass so coated, held in front of a lamp in perfect action, will make it appear like a red-hot wire: in fact when a lamp appears to be giving only a dull glow, this is the most common cause of the failure.

1012. DISTRIBUTION OF LIGHT.—Like all radiant actions, the intensity of light varies inversely as the square of the distance from the source. This is the necessary consequence of the fact that the *surfaces of spheres vary as the square of their radii*; each point in space is part of the surface of a sphere, formed on a radius which is the distance of the light source, and therefore as the light is divided over a total area increased as the square of the radius, the quantity available on each unit of area must be inversely as that value.

1013. This will illustrate the idea expressed § 993. A source of light may be regarded as an agent for converting potential energy into kinetic energy, which it continually radiates away in spherical waves. This energy traverses *pure space* with little, if any, reduction, though it is absorbed by matter under conditions explained § 988. At each spherical extension the wave is spread over a larger area, therefore its amplitude or height is lowered, and the energy in it per unit of area is reduced; that is to say, the *density of the energy* is lowered in proportion to the *square of the distance* it has traversed.

1014. This is an important consideration in applying light to practical use. A light of very great power may be uselessly intense at one part, and unequal to the required effect at another. As a rule also, several lights distributed about an area are better than an equal light at one part, because they break up the deep shadows a single light must throw. A very intense light is also injurious to the sight: it is said that we need not look at it, neither need a moth fly into a flame, and light draws the eye to it as the flame does the moth. For convenience it is certain that a small light, close by, is preferable even to the same degree of light from a distant source: it is also certain that better results are obtained, throughout a space, from lights evenly distributed, than from a light of three times the nominal power at a single point. The result is that notwithstanding the low cost per candle of arc lamps of great power, they are unsuitable for internal uses and less economical than the more costly incandescent lamps.

1015. ELECTRICITY AS A SOURCE OF LIGHT.—This has attracted great attention lately, not that it is a new discovery, for Davy made it in 1809, and exhibited an electric arc four inches long in air and seven in vaçuo. Great also as recent improvements appear to be, there is really little more known on the subject than has been known for many years; this may be seen from King's specification published in 1846. The truth of the matter is that electricity was too dear to use for this purpose until the dynamo machine became a practical thing. Then Jablochkoff introduced his arc "candle" which was seen by all the world in Paris in 1878, and took the public imagination by its claim to do away with the intricate mechanism of the light "regulator"; but the candle, as a matter of fact, had objections of its own of much greater moment than those it professed to overcome. Public ignorance led to the expectation that the supposed new light was to utterly supersede gas, and the statements made by or attributed to Mr. Edison added to this delusion, which was no doubt fostered by interested people. The result was a perfect panic in shares of the gas companies: 100*l.* stock of London companies which in January 1878 were worth 188, had fallen to 160 in January 1879, and I believe went down to 140. That same stock in January 1884 was at 250*l.* and no announcement about electricity moves it 1*l.*, while the electric lighting shares are a sore subject to a good many people.

1016. But electric lighting, while it will not do what was expected, and will not probably supersede gas, or injure the interests of the gas companies, has a great and important field before it, which it will cultivate by degrees. Its real progress thus far has consisted in practical working out of facts well known before, and in the elaborating of details, now important, but which were not studied thoroughly until there was a prospect of their being of some value.

1017. *The electric light is not produced from electricity.* This is the rock upon which many inventors have wrecked themselves. Even scientific writers often speak of the *conversion of electricity* into light, but this is an error, as shown § 351. We do not burn electricity as we do gas or oil to produce light, and even the gas and oil are not converted into light, but into carbonic acid and water; the source of their light is their potential energy, set free as heat in the act of combustion, § 517. The process by which this heat gives light is the raising to white heat of solid particles of carbon, momentarily set free from their combined hydrogen, which is burnt first, those particles which if the flame is cooled, appear as soot. This may be shown by a Bunsen burner, giving a blue flame, with intense heat and no light, because the mixed air burns the whole of the gas: fine dust of any kind, but especially carbon, as lampblack sprinkled into the flame, at once makes it luminous.

1018. Strange as it may sound, the process of generating light is *identical in the tallow candle, the gas flame, the electric arc, and the incandescent lamp*; in all of them the light proceeds from intensely heated particles of carbon.

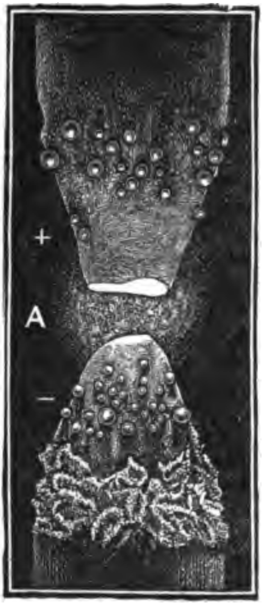
It is ENERGY *that is converted into light in all cases.* It is the *cost* of the energy and its *density* in each kind of light, which constitute the ratio of economy and efficiency. We may even go a stage further and say that the process of developing energy is the same in all cases. In the tallow candle we have a crude gas retort in the wick, which draws the melted fat up to a point at which it is exposed to a heat at which it is vaporized, and then burnt. In the gas factory we have the same process, more perfectly carried out, and a purer gas produced. The fire of the steam boiler fulfils the same function for the electric light, and by the aid of the dynamo machine eliminates all the material residues, and delivers *pure energy* at the point of application.

1019. Here is the true distinction among the lights; with the oil and the gas, we generate the energy in presence of the waste materials of the process, and a large part of the energy has to be expended in heating and carrying away the resultant water and carbonic acid, and the residuary nitrogen of the air. These have to be equally got rid of in the electric process, but it is done at a distance; therefore we are not limited to the quantity of energy contained, potential, in the matter itself, less that necessarily lost; we can concentrate the energy itself, electricity is its vehicle, instead of combined matter, and surrenders it in the act of lowering its potential.

1020. The result is that in lighting by combustion, the "density of the energy" is limited, and in each case can only rise to the temperatures shown in the table of flames, § 996, while, in the electric light, the only limit is the capacity of the matter in which the light is generated—the temperature to which it can be raised. This brings us to the two systems of electric lighting: by the *arc*, and by *incandescence*.

1021. THE VOLTAIC ARC.—This is the name given to what is really a constant "brush discharge." That produced by friction machines, § 84, is due to the great E M F existing between the conductors, which breaks down the great resistance of the air: it is, however, a current more or less sustained, and gives a light proportioned to the energy present in it, and related (§ 100) to the matter in the space and that carried from the poles. The *arc* forms under a comparatively low E M F, which is compensated by the reduced resistance of the air, due to its being intensely heated. As a consequence, the arc cannot be developed across an open space; it is necessary for the conductors to touch so that the current passes, and then to be separated gradually. During this action, the current heats the air and vaporizes a portion of the conductor, thus filling the growing interval with a gaseous conductor, and with a light proportioned to the energy transmitted to, and expended in this conductor, according to the general law of $C^2 \times R$.

FIG. 118.



1022. The appearance of the arc is shown, Fig. 118, as seen through dark glasses by aid of a lens which magnifies it.

This figure shows such an arc as is obtained with the old retort carbons, rather than with the best modern artificial ones: the globules are caused by the silica, iron, and sulphur present in the graphite, from which the prepared carbon is partly purified. The + carbon is usually the uppermost, and being the more highly heated by the current, burns away the most rapidly: particles of it are carried off and transferred, as in electrolysis, to the − carbon which forms a pointed cone, while the + carbon forms a hollow crater of intense brightness, and acts as a sort of condenser to throw a large proportion of the light downwards.

1023. *Temperature of the arc.*—The latest researches give a high value for this, and Becquerel found it 2100° centigrade; while Rosetti, after numerous experiments, gives

	+ Carbon.	Arc.	− Carbon.
With 80 Bunsens	2870	3500	2400 Cent.
Maximum ..	3900	4800	3150 "

It is evident that the temperature of the carbons must be varied with their dimensions, and that their rate of combustion will also be affected; but it is stated that the temperature of the arc is independent of its *thickness* or of the current passing. On the other hand, it is lower as the E M F lowers with reduced number of cells, which would reduce the *length* of the arc.

The most refractory minerals fuse and volatilize in the arc, and even iridium softens, and if not pure may be melted. And as it dissociates most substances and reduces them to the elementary condition, it is the most powerful instrument of analysis we possess.

1024. *The light of the arc* is compound, consisting of the pure white light from the incandescent carbons, and the specific bright rays of the incandescent gases of the arc itself: the first of these is even whiter than sunlight, because this has lost the rays belonging to the dark lines of the solar spectrum, and much of the violet end, which is absorbed in passing through the atmosphere, thus leaving an excess of yellow even in sunlight, which excess is even greater in gas and oil flames in proportion to their lower temperature. But the light of the arc consists of a faint continuous spectrum from the incandescent solid particles, and bright rays of specific gases, nitrogen and carbon, which are principally in the blue and violet: these give the steel or aluminium glitter to the arc light, which is so ghastly in its effects, and unfits this light for internal domestic uses. The shorter the arc space, the whiter the light becomes.

1025. *Colours by arc light.*—A consequence of this is, that while coloured objects are brought out with great vividness, they are not seen in either natural or pleasant tints. At first, a great advantage was claimed for the electric light on this head, because blues and greens are not properly seen by gaslight, owing to the deficiency of the blue rays. But the excess of these in the arc has its own drawbacks, as all whites and most light colours are overborne, because they reflect all the rays to some extent as well as their own specific colour. This is strikingly seen when a fruiterer's shop is lighted up by arc lights; we can see at once that the variously coloured fruits have a most unnatural and harsh appearance.

1026. *Penetrating power* depends upon the intrinsic brightness of a light, and upon the quality of the rays it emits. Intrinsic brightness is not affected by distance, that is, light is not absorbed in traversing pure space, so that if we look at two exactly equal lights, one near at hand, the other miles away, through a pin hole which is filled by the light, but limits the active area, we cannot distinguish them, if the air is quite clear. The apparent effect of lowered brightness is due to the different quantity of light falling on the opening of the eye, or in fact to the angle filled by the light. But in passing through ordinary air, the fine particles of dust and moisture take up particular rays and diffuse them, which is the cause of the blueness of the sky and of water. The electric arc light is greatly influenced in this way, and even in lighthouses, where the vividness of the concentrated beam is so valuable, it is found to fail in penetrating power when fog occurs.

This may be seen on Westminster Bridge whenever the night is misty; the road along the Embankment has the Jablochkoff candles on the water side, and the common gas lamps on the other side of the road; at a certain distance they become indistinguishable in spite of the great difference in their light power: a little further, and the gas-lamps may be seen while the others disappear.

1027. The *resistance of the arc* has been very differently valued. Siemens has given it as about 1 ohm; W. H. Preece 1 to 3; while Ayrton and Perry, with varying battery power in Bunsen cells, give it as 12 ohms with 60 cells, 20 with 80, and 30 with 122, growing more rapidly than the resistance of the battery.

The reasons of these differences are, (1) that there is probably a counter E M F set up, dependent on the work done in the arc, and possibly resembling that described § 602; (2) the resistance is actually a function of the current itself, and the values are calculated, not actually measured.

Schwendler found that with an arc of fixed length the *resistance varies inversely as the current:* this is readily comprehended when we see that increased current does not so much affect the existing arc as increase its sectional area by introducing more conducting material, so that the arc acts as an expanding pipe would with water.

An elaborate set of experiments and calculations by O. Frohlich will be found in the *Electrician*, vol. xi. p. 150, which show that in the same arc the resistance may vary from 1 to 40 ohms according to the current passing.

1028. The *EMF in the arc* varies with its length, and according to the latest experiments of Professors Ayrton and Perry, as a curve corresponding to that of "length of spark" in De la Rue's experiments, § 101. They found that an arc of one-tenth of an inch requires 60 volts, increasing quickly up to a quarter inch, and after that at the rate of 54 volts per inch. The experiments of Frohlich, § 1027, while giving a very irregular set of spots approximating to a slowly rising line, are quite consistent with such a curve.

1029. *Products of the arc.*—Mr. Wills announced the production of nitrous acid very soon after the introduction of the Jablochkoff candle, and Professor Dewar gave the matter a close examination. Besides the nitrous acid, of which Mr. Wills collected 12 grains per hour from an arc lamp, there are produced acetylene and prussic acid, chiefly at the + carbon. Professor Dewar used hollow carbons to draw off the products of the arc by suction; it does not follow, therefore, that either of these products escapes to any great extent, as they would be oxidized towards the outer surface of the arc. But the nitrous products resulting from the union of the nitrogen and oxygen of the air, and most probably as a secondary result of the oxidizing of the prussic acid, must pass into the atmosphere. In fact, they can always be smelt wherever arc lights are burned in inclosed spaces. This was very strongly noticeable at the Crystal Palace Exhibition, in the chamber occupied by the Brush Company: it is probable, that in this case the effect was partly due to ozone generated by the sparking of the several large machines at work. No doubt many people found themselves with sore throats which they attributed to colds, but which were really due to these nitrous fumes. This subject deserves attention, because much injury is attributed to gas because of the acids produced from the small quantity of sulphur it contains, and it is certain that nitrous acid can be no less injurious, while most of the carbons contain sulphur, and this is also converted into sulphurous acid in the arc. Of course, there is carbonic acid also produced equivalent to the carbon consumed; as ordinary gas contains about 1·34 grains of carbon per foot, it is evident that in the arc lamp every grain of carbon consumed corresponds to ·75 feet of gas burnt in the same time. Therefore 5 feet of 16 candle gas gives per candle a consumption of grain ·4 per candle as compared with the figures, § 1046 for arc lamps.

1030. *Applications of the arc light.*—It is best suited to exterior purposes, as for carrying on open-air work at night: it is also useful in factories, where a general illumination is required over a large area, rather than at individual points. The best mode of using it in such cases is under a curved roof or screen for a reflector, the lights themselves being suspended under the roof, with a semi-transparent reflector below them, which prevents the lights themselves from being seen, and takes up part of the direct rays, and distributes them to a distance by direct reflection from the upper surface.

The *fluctuating character* of the arc light renders it specially unfit for reading-rooms, as being injurious to the sight from the constantly changing adjustment of the eye required: the semi-incandescent systems would be far preferable to the pure arc, while inferior to the purely incandescent lamps.

1031. *Position of the carbons.*—As the arc is formed in a mass of incandescent vapours, it is carried upwards by the ascension of these, § 1032, whence, in fact, came the name of *arc* from the curved form assumed between two horizontal conductors. Therefore, the position of the two carbons affects the working of the light, and it was proved long ago that, placed vertically over each other, they give better results than when in a horizontal line.

The *distribution of light* from an arc lamp is not uniform in all directions, because it is not a luminous point, and as the lines of light issue at right angles to the surface, the form of the carbons influences the quantity radiated in any direction. Figs. 119 and 120 illustrate this. In Fig. 119 the carbons are in one vertical line, + uppermost, as in Fig. 118, so that equal diffusion takes place all round in the horizontal line, as occurs also with the two tapering points produced by alternating currents, which also give a more equal diffusion in other directions. When a strong beam is required in one direction only, and reflectors are used, as in lighthouses, the carbons may not be arranged in one vertical line, but with the front of the upper carbon in a line with the middle of the lower one. In this case the hollow crater is not formed, but the carbon burns away in a curve, as in Fig. 120, forming a background, from which the light is thrown mostly towards the front; and the light is steadier also, owing to the more regular combustion. In Mr. Douglas's experiments at the South Foreland it was found that with this arrangement the light given, taking the direct vertical arrangement as 100, was:—

East or front	287
North or side	116
South or side	116
West or back	38
Mean = 139.	557

When an interior illumination from above is desired, as in § 1030, the + carbon should be below, in order to throw the light upwards.

Fig. 119.

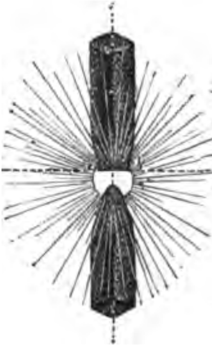


Fig. 120.

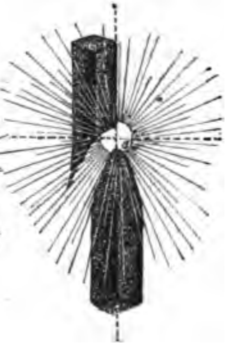
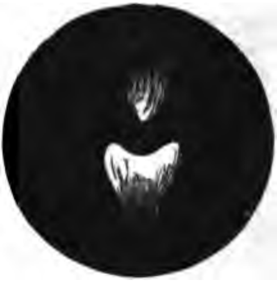


Fig. 121.



1032. Heat-Rays.—It was shown, in § 988, that the light-giving rays could be sifted out from the total radiation; the remaining heat-rays may then be employed to reverse the process of "fluorescence," § 990, as they, being invisible rays of long wave-length, may generate rays of quick vibration. Tyndall did this by condensing them upon a sheet of thin platinum which they heated, and so produced a distinct picture of the carbons and arc, drawn in degrees of light. The picture is shown, Fig. 121.

It will be seen that there is a dark space between the two carbon points; this space corresponds to an intensely heated portion of the arc in the intervening space, while the lighter portions represent the incandescent carbons, in which lower temperature prevails. This is owing to the incapacity of gases to *radiate* heat, which, therefore, is carried away by convection, § 490, in a stream of heated air: besides, the rays in this space are the special ones of the gases themselves, and light-giving in so far as they can be radiated.

1033. Arc Lamps.—It is evident that, in order to maintain the arc in uniform condition, some means must be adopted to compensate for the consumption of the carbons: if this consumption were perfectly regular, a mechanical feed might be used to move the carbons forward at the same rate as they are consumed; and even ordinary clock-work could be made to do this at different rates corresponding to the required conditions of light, current, &c. But the carbons do not burn away uniformly, and every little irregularity of purity or texture varies the conditions of combustion, and distorts the form and length of the space in which the arc exists. The object of the "arc lamps," or regulators, is to provide this varying compensation, and make the different variations correct themselves. The number of arc lamps is so great and increasing, that it is impossible to attempt any description, and therefore nothing further will be attempted than a general explanation of the principles of action.

1034. There are two distinct systems in use. (1) *Gravitation*, or spring pressure, may be used to bring the carbons together, and then the apparatus separates them so as to fulfil the conditions of § 1021: then the weight continues the feed, controlled by this separating action set up by the magnetism developed by the current which feeds the lamp. (2) The differential influence of two magnetic actions of the current may be utilized to maintain a uniform resistance in the arc, or a fixed rate of current, or preferably a fixed difference of potentials, which being independent of the currents, enables several lamps to be worked independently on one circuit.

1035. In the most elementary form of regulator the upper carbon slides in a metal clip by its own weight; one side of the clip is connected to the armature of an electro-magnet, which causes a pressure increasing with current, so that when the current is reduced by the growing resistance of the lengthening arc space, the pressure diminishes, and the carbon slides down, till the growing current again stops its motion.

1036. *Serrin's* lamp, which was the best and almost only one in use before the revival of 1878, is an automatic development of this simple type. The + or upper carbon is suspended from a rod which slides vertically, and tends to descend by its own weight; the lower end of this rod is a rack gearing into wheelwork, fitted with a fly to control this descent. The – carbon is also fixed on a sliding rod, which is so worked by a chain to the wheelwork, that it ascends through half the distance through which the other falls, so as to keep the carbon points at one level.

The regulation is effected by a rocking frame, difficult to describe, even with the aid of a diagram, the motion of which is resisted by springs adjusted to suit the required arc; this frame causes an armature to be attracted by an electro-magnet, and also a ratchet-pawl playing between stops, which checks the motion of the wheelwork. When no current is passing gravitation brings the carbons together and closes the circuit; when current passes the frame is drawn down, and the carbons lifted apart, so as to form the arc; then the strength of the current controls the action of the detent, and the rate at which the carbons fall together.

Great improvements have been effected in this lamp to adapt it to the later requirements.

1037. The Siemens or Von Alteneck lamp, which has been much used in lighthouses, carries out the same principle of action as the Serrin, by different mechanical arrangement. The two carbon carriers are geared together by wheelwork so as to keep their junction at one level; and the framework of the Serrin is replaced by a rocking lever which gears into the wheelwork, and is vibrated by an electro-magnet so as to separate the carbons.

1038. The *differential* principle can therefore be explained by this construction of the Siemens lamps. The bar is actuated by a long iron core which enters into two solenoids, so that its position is regulated by the difference in the attractions these exert. One consists of a coil of stout wire carrying the current which gives the light, and its action separates the carbons. The other is a shunt circuit of high resistance, and tends to draw the carbons together. The two actions balance when the defined difference of potential exists in the arc. If the arc is too wide, the ratios alter; more current passes the shunt coil and it allows the carbons to approach.

1039. This description is of course not intended to explain the full action of the lamp, but only to set forth the differential principle, which in various modes is now used in the new arc lamps. It appears to have been first employed by Lacassagne, in 1856: he used it to control the quantity of mercury in a chamber, so as to adjust the carbon levels, which system has also been utilized by later inventors.

1040. *The Werdermann lamp* may be taken as a type of a number of semi-arc lamps, such as the Regnier and the Joel. It consists of a convex block of carbon, against the middle of which a rod of carbon is pressed: the result is a partial arc of low resistance and much steadiness; the resistance of the imperfect contact causes part of the current to form derived circuits in the heated air, and to burn away all round the end so as to keep it pointed; the point is also in a state of bright incandescence which extends for some distance, while the upper carbon, being made the − pole, and being so much larger, is little heated. This system has its advantages, but is less economical than the pure arc, while more steady.

1041. *The Sun lamp* or "Lampe Soleil," is also a semi-incandescent arc lamp in which the carbon ends rest in channels in a block of lime or other suitable substance, such as compressed magnesia, which is powerfully heated by the arc; the light is really produced from this incandescent substance, and is therefore more steady, and not so violet as the pure arc lamp. This plan is really a union of the Jablochkoff candle and the old oxy-hydrogen system, in which a block of lime, raised to incandescence by the heated gases, is the source of light. It is very like one of the lamps invented by Staite in 1846.

1042. JABLOCHKOFF CANDLE.—This was devised to do away with the necessity of regulating the arc by mechanism. It effects this regulation by adjusting the distance of the carbons permanently, side by side, using alternating currents to insure equal consumption in both. The carbons are mounted in brass tubes, by which the contact is made, and separated by a layer of plaster of Paris, and at the lower end by a cement which surrounds the carbons and tubes and binds the whole together. A strip of plumbago and gum joins the upper ends of the carbons, and so enables the current to pass and form the arc; but if this is once extinguished there are no means of re-lighting the candle. The plaster of Paris becomes heated, and is then a partial conductor, carrying a portion of the current, becoming vividly luminous; it however produces the intermittent rosy tinge which frequently flashes into the light. As the candles burn only 1½ hour, a lamp is used which contains four candles, with wires and a commutator at the foot of the lamp to throw the current into any desired one of the candles.

The light is more unsteady than that of any inferior arc lamp; and the light generated for the energy supplied is much below that of any good one. Count du Moncel placed a candle and Serrin lamp on two similar circuits of a machine, and found that the lamp gave three times the light of the candle. According to the best accounts they give about 450 candles in their best direction, the horizontal line, which the opal globes reduce to 172, and to about 90 on the ground. Faintly ground globes are now used in this and other lights to diminish this loss of light, with the disadvantage that the glare is so great as to dazzle the eye.

1043. *Modified "candles."*—The great temporary success of the Jablochkoff candle led naturally to several imitations, such as those of Jamin and De Meritens, in the latter of which a third intermediate carbon is used, not in the electric circuit, but as a stepping-stone which divides the arc into two. The Wilde form overcomes the objection to the older form that if the light goes out it cannot be started again: one of the carbons is mounted upon a hinged support attached to the armature of an electro-magnet, so that when no current passes, this carbon falls over and brings the two ends together, closing the circuit and re-establishing the arc, then the electro-magnet becomes active and draws the carbon away.

1044. CARBONS.—At first the charcoal of wood was employed but was replaced by the graphitic deposit of gas carbon, cut into square rods: but this not only contains sulphur, iron, and silica, but is of very irregular texture, and traversed with fissures; all these causes result in great variation of the light, and artificial carbons alone are now used. These are produced from various forms of carbon, and different makers employ different processes of purifying the carbon and making it up. Some use the retort carbon finely powdered, and boiled with alkalies and acids to remove the impurities; others employ lampblack: the agglomerating materials are gum, starch, sugar, and pitch. The materials are worked into a tough paste, pressed into rods by the hydraulic process, gradually dried in moulds, or so arranged as to keep them straight, then slowly heated up to a red heat, in coke powder contained in retorts, to drive off everything that can be vaporized. The rods are then soaked in strong syrup, or in dissolved pitch, and again dried and carbonized; the process is repeated till all porosities are filled up and an extremely dense substance is produced, having a metallic ring and a fracture like hard steel.

The process of heating the carbons in a hydro-carbon vapour, first employed by Sawyer and Mann, and used by several makers of incandescent lamps, is employed also for arc carbons, which can be packed in a suitable retort and heated to incandescence while a stream of vapour of gas-tar is driven through the retort; this process is in fact identical with that which produces the gas carbon itself, only conducted under conditions to control and facilitate the deposit.

1045. The presence of various salts affects the light, thus, salts of sodium tend to increase the yellow rays, and are said to lengthen the arc and diminish the hissing sounds produced; borax also tends to reduce the consumption by fusing on the surface and diminishing the access of oxygen; but it appears doubtful whether there is advantage derived from any additions except the thin coating of copper which is employed in some cases to lower the resistance.

1046. *Different makes* of carbon consume at different rates with the same current and light, and it would appear that those based upon uniform materials give best results: that is to say, the carbon is a lampblack derived from burning pitch, and the cementing material the same pitch dissolved in naphtha.

The *consumption of carbon* is about twice as much at the + as at the – conductor, and the total appears to be about grain ·06 per candle of light per hour in the Jablochkoff system, and from ·1 to ·05 in the arc lamps, diminishing as the power of the lamp increases.

1047. INCANDESCENT LIGHT.—The fact that light could be produced by the electric current passing through highly infusible materials was known early in this century. Platinum, iridium, and carbon were all examined, and in 1845 King patented lamps of carbon in vacuo, while De Changy made successful attempts of the same nature in 1858. Therefore the recent progress in this direction relates not to principles, but to the details and the most effective mode of carrying the principles into practical effect.

The laws of generation of heat by the current are explained § 354, and the generation of light by this heat in the early part of this chapter, but it is necessary now to examine some of the facts more closely.

1048. *Atomic or Molecular Heat.*—In § 12 it is mentioned that heat acts upon matter according to the atomic weights, and not according to the weight or mass merely: this is shown more fully in relation to matter in the gaseous form, § 593. But many facts indicate that it is not really the atomic weight, but the *molecular* weight that we ought to consider, for the same substance in the elementary state may have different relations to heat; this is particularly the case with carbon in its several forms: this fact is strikingly exemplified by many instances now known, in which a substance undergoes some unknown change at a particular temperature, by which its properties are altered; iron undergoes such a change in cooling from a great heat, and gold gives a striking illustration of such a change. When melted and super-heated, it will cool gradually and quietly till, at a certain stage, it suddenly heats spontaneously and glows vividly, after which it goes on cooling quietly. These *critical* points, as they are called, probably correspond to a new molecular arrangement of the atoms, to a passage from one allotropic state to another, in which a different quantity of energy is combined with the atoms, and the sudden heating is due to the potential or latent energy of one form giving up the excess of that needed for the other form: in all likelihood the number of atoms built up into one molecule is altered at this instant, with other changes of physical property, as in the case of ozone O_3 and oxygen O_2 described § 589. It appears highly probable that such a change as occurs under these circumstances may be connected with that variation of chemical affinities by which gold, for instance, is univalent in aurous salts as the cyanide, and trivalent in auric salts as the chloride, and so generally with those metals which form two or more sets of salts of differing valencies.

The result is that the same quantity of heat produces different temperatures in equal weights of the same substance; but, subject to modifications indicated § 593, a fixed quantity of heat will raise an equal number of molecules of different substances, in the same physical state, to the same temperature.

The atomic heat is the product of the atomic weight and specific heat, § 355, so that we have

Platinum $197 \times \cdot 0355 = 6 \cdot 99$
Graphite $12 \times 2018 = 2 \cdot 42$

We have, however, chemical evidence that graphite is essentially different from *carbon*, of which we use the atomic weight 12; that is, it is allotropic carbon, and if we reckon the molecule of platinum as 2 atoms, and that of graphite as consisting of 5 atoms, we should have nearly equal molecular heats. But this is a mere hypothesis at present, and these figures are given to show the variety of actions involved in the production of light, awaiting further knowledge for their actual application.

1049. *Atomic or Molecular Volume.*—As different substances hav edifferent molecular weights, and also different specific gravities, it is evident that in a conducting wire, which, § 468, is primarily a *volume* or defined space, we may have very different numbers of molecules taking part in the action, and therefore different relations to heat; these relations, like resistance, vary also with temperature, which alters volume differently in different substances.

$$\frac{\text{at. wt.}}{\text{sp. gr.}} = \text{at. vol.} \quad \text{Platinum}\left\{\frac{197\cdot}{22\cdot 1}\right. = 8\cdot 91. \quad \text{Graphite}\left\{\frac{12\cdot}{1\cdot 06}\right. = 11\cdot 4$$

Now if we multiply together these figures of atomic heat and atomic volume we get for platinum 59·3, and for carbon 25·6, as the comparative temperatures to which equal heats might raise wires of the same diameter.

1050. *Specific Resistance*, p. 283, Col. III., and that modified by the variation due to temperature, would have to be taken into account in considering the effect of equal currents, and we have not as yet sufficient facts to make it worth while going further than to thus indicate a course of probably interesting research.

1051. *Radiation Capacity.*—Not only has each gas its own spectral lines, § 988, but each solid substance, while generating all the rays corresponding to its temperature, has a capacity for generating or emitting specific rays in greatest abundance; thus, if a piece of white earthenware with a dark pattern upon it be heated in a furnace, when seen in the dark by its own light, the dark pattern will appear the brightest, that is to say, it will emit the light-rays of the spectrum more freely than the white ground, though both are at the same temperature. If a platinum wire be partly polished and part roughened, the rough part will be brightest when heated: also, a piece of glass and of iron being heated in a furnace to the same heat, the iron will be bright, while the glass will give little light; on the other hand the glass would be found to emit more of the dark rays than the iron. Carbon has this property in a high degree, and it appears probable that if all other conditions were equalized, carbon would emit more light than platinum.

1052. The following extracts from a lecture given in Newcastle, by Mr. Swan, 20th October, 1880, will give the most interesting account of the origin of the incandescent lamp. After describing Mr. Edison's experiments with platinum, he says:—

> "It had appeared to me for many years, that if ever electric light was to become generally useful, it would most probably be by the incandescence of carbon. I had, long before the time to which I am referring to, rendered this idea practicable. As a matter of history, I will describe an experiment which I tried about twenty years ago.
>
> "I had a number of pieces of card and paper, of various forms and sizes, buried in charcoal in a crucible. This crucible I sent to be heated white hot in one of the pottery kilns belonging to Mr. Wallace, of Forth Banks. . . . . My carbon was in the form of an arch, about one inch high and a quarter of an inch wide; the ends of the arch were held in small clamps with square blocks of carbon.

The air-pump having been worked, I had the pleasure of seeing that with the battery of 40 or 50 cells, my carbonized paper arch became red hot, and that nothing more was wanted than a still stronger current to make it give out a brilliant light.

"That, I confidently believe, was the very first instance in which carbonized paper was ever used in the construction of an incandescent electric lamp. I am now speaking of twenty years ago, and at that time the voltaic battery was the cheapest source of electricity known, and the means of producing high vacua were very much less perfect than they are now. I laid my electric light experiments aside till about three years ago, when two things concurred to lead me to pursue the subject afresh.

"The discovery of the dynamo-machine had entirely altered the position of the question of electric lighting. The Sprengel air-pump too had been invented, giving much higher vacua than the old form of air-pump. Mr. Crookes' radiometer experiments had shown us what a really high vacuum was, and how to produce it.

"I had the good fortune to make Mr. Stearn's acquaintance (who had acquired such a knowledge of the Sprengel pump as was only equalled by that of Mr. Crookes himself), and that was one of the determining causes of my second attempt to solve the problem of electric lighting by the incandescence of carbon.

"In October 1877, I sent to Mr. Stearn a number of carbons made from carbonized cardboard, with the request that he would get them mounted for me in glass globes, and then exhaust the air as completely as possible.

"In order to produce a good vacuum it was found necessary to heat the carbon to a very high degree *during the process of exhaustion*, so as to expel the air occluded by the carbon in the cold state. In order to make a good contact between the carbon and the clips supporting it, the ends of the carbons were thickened, and in some of the early experiments, electrotyping and hard soldering of the ends of the carbons to platinum was resorted to."

1053. It was in the latter part of 1878 that Mr. Edison turned his attention to incandescent lighting, and it would appear that the actual intended invention, the announcement of which produced the panic referred to § 1015, was really one of which nothing has since been heard, viz. a semi-conducting incandescent material compounded of infusible earths and carbon or metals. I had myself patented a nearly identical idea within eight days of the date of Mr. Edison's patent, and had tested and found it worthless, while the scare was in full vigour; and I may say that the idea was suggested to me by the vivid light shown by Jablochkoff at the 1878 Exhibition, derived from a thin strip of plaster of Paris made incandescent by an induction coil.

1054. Mr. Edison then took up platinum and made a very good lamp, based upon his re-discovery of the effect of gradual repeated heating in rendering platinum more coherent and infusible; but even this would not stand working, and then his admirable perseverance in the endeavour to accomplish what he had promised to do, led him to try carbon, and in his patent of the 10th November, 1879, he speaks of using "carbon wires," and says he has discovered that even a cotton thread properly carbonized is absolutely stable at very high temperatures in a sealed bulb exhausted to one-millionth of an atmosphere. His inexhaustible experimental energy led him to examine almost every imaginable carbon-producing substance, and after Bristol board punched out, he ultimately settled upon bamboo shaped into suitable form.

1055. As to the order of discovery, Mr. Swan went on to say:—

> "In an article which appeared in the February number of *Scribner's Magazine*, authenticated by a letter from Mr. Edison in the same publication, it is stated that Mr. Edison was the first to use carbonized paper; that is incorrect. And this also occurs after a description of Sprengel's pump used in exhausting these lamps: 'Mr. Edison's use of carbon in such a vacuum is entirely new.' Now, I dare say there are many here who will remember this little lamp, which I showed here two years ago in action. This lamp has exactly the same simplicity as my present lamp, being composed entirely of three substances, viz. glass, platinum, and carbon, and it was exhausted in precisely the same manner, and to the same degree, as that which Mr. Upton—no doubt in good faith, but still in error—speaks of as '*entirely new.*' I do not mention these things in any way to disparage Mr. Edison, for no one can esteem more highly his inventive genius than I do. I merely state these facts because I think it is right to do so in my own interest, and in the interests of true history."

1056. As a matter of true history, neither Mr. Swan nor Mr. Edison have any claim (though this was set up and promised a fruitful harvest to the lawyers) to the use of carbon and vacuum, singly or combined. They used a finer *thread* or *wire* of carbon than previous experimenters, or at least than others were publicly acquainted with, but this gave no right to material or size, for others had only been limited in this matter by the difficulty of producing very thin carbon rods: every one had sought to use as perfect vacuum as possible, and there was no discovery in using the improved vacua open to every one for any purpose. The real improvements of both claimants consist in the modes of obtaining a "carbon wire," and in the details of the construction of the lamp itself.

The *incandescence of carbon in vacuum* was patented by King in 1845, and invented by Starr, an American, associated with King in electric lighting: they used the best vacuum then attainable, that produced in a barometer tube, and Mr. Mattieu Williams, who was working with them, says, "we had no difficulty in obtaining a splendid and perfectly steady light. We used platinum, and alloys of platinum and iridium, and then tried a multitude of forms of carbon, including burnt cane."

M. Jobard in 1838 published the idea of using a small carbon as a conductor of current in a vacuum; and M. de Changy made effective lamps of this kind which were submitted to the Academy of Brussels in 1858.

1057. It is remarkable that the two leading inventors of the carbon lamp, Swan and Edison, each claim a *definite principle* in producing the carbon wire. Mr. Swan takes an organized structure, crotchet cotton, and destroys that structure by acting on it with acid, so as to reduce the cotton fibres to a gummy substance before carbonizing. Mr. Edison uses the bamboo fibre because it has a definite structural form. It may be that the presence of silica plays an important part in the Edison lamp, but it is very evident that neither of these principles can have any importance.

Other names must not be overlooked, and Mr. St. George Lane Fox ranks nearly parallel to Swan and Edison in the introduction of incandescent lighting, though for some reason his lamp is rarely heard of now. There is, however, no pretension in this work to examine questions of priority or merit, except incidentally and in the course of description.

1058. The differences in the various lamps consist in details, some of which require separate consideration.

(1) *Form of carbon wire.*—The *Edison* is a tall arch; the *Swan* is a similar arch, of which the upper part makes a spiral of one turn of half an inch diameter. The *Maxim* is a longer carbon folded up in the form of M. All this is not a mere matter of form; they act very differently upon the eye: when the "wire" is incandescent it appears to be very greatly increased in size; this is an optical effect in the eye itself, a result of *irradiation*: The result is that a grating of wires near each other appears to blend in one mass of light which is less distressing to the sight than an equal quantity of light issuing from one distinct wire; thus a Maxim light is more easy to the eye than an Edison of equal power, and the Swan is intermediate.

(2) *Dimensions of carbon.*—These are governed by the same principles as the heating of wires, § 354. Therefore the light given is proportional to the *length* of equal wires, subject to the greater loss of heat in short wires by the more rapid cooling through the connections: for this reason incandescent light is readily subdivisible with little loss, while arc lighting suffers a loss at least as the square of the division, and is only possible for lights of large intensity.

The smaller the wire the greater the economy, because of the facility of generating high temperature: but this reduction is limited by the capacity of the material to endure the temperature without speedy destruction.

The best *diameter* is still a subject of experiment, and will yet be influenced by improvement in the structure of the carbon itself. The Swan lamp carbon is about 0·25 mm. in diameter, and the Siemens 25 candle is 0·27 mm., both of circular section, whilst the Edison 16 candle carbon is of oblong section, with sides 0·1 and 0·2 mm.

Lamps are also made of much larger sections, such as Bernstein's low resistance lamp, formed of a hollow cylinder of carbon, so as to obtain large radiating surface with small quantity of material, which appears to be based upon principles the reverse of those found to give the best results by other makers.

1059. *Different materials* are employed to produce the incandescent wire. The carbon threads, or more properly "carbon wires," could not have been imagined a few years ago. It is true we are acquainted with carbon in forms so different as not to be recognizable as the same substance, as the intensely hard transparent diamond, as the friable charcoal, and as the crystalline graphite; but none of these could be conceived as forming a slender filament of any strength or durability. But the "wire" of the incandescent lamp as now produced is really a *wire;* it is strong, tough, and flexible to a degree comparable with metals, and therefore will bear the inevitable shocks of transport. Its appearance also is that of a grey granular metal, not unlike coarse steel in fracture.

(1) The *Swan lamp* carbon is made from cotton thread, parchmentized before carbonizing, and twisted up in a loop of half inch diameter, and strongly heated during the final exhaustion. The platinum conductors form two loops at the base of the lamp, and these engage in hooks in the support, which form the connection to the circuit, and good contact is secured by the upward pressure of a spiral spring. This gives a freely elastic support to the lamp, which for its perfect simplicity and efficiency, together with ease of fitting up and security from injury, is scarcely to be surpassed.

(2) The *Edison carbon* is made from selected bamboo, slit to the required thickness, and then cut out to the proper width, with enlarged ends for good junction to the platinum conductors; the junction also has copper deposited upon it. The base of the lamp is made with a screw thread, by which it is fixed to the fittings, and it closes its circuit in the act of screwing in.

(3) The *Lane Fox* carbon is prepared from the vegetable fibre used in making brooms. The wire is heated to incandescence in a carbon vapour in order to increase its density and adjust its resistance to the required point. The platinum wire from

the carbon does not come to the exterior of the lamp, but ends in a small tube containing mercury: copper wires, passing through a wooden cap and a mass of plaster, also dip into this mercury and form the actual terminals.

(4) Prof. Crookes endeavours to perfect the carbon by acting on it with chlorine and other agents to dissolve or vaporize impurities. Mr. Fitzgerald adds a magnesium wire which, after final sealing of the lamp, is heated so as to take up any residuary oxygen. Others propose to build up a carbon bridge by filling the globe with a hydro-carbon vapour, and passing sparks from an induction coil between the two platinum wires, so as to produce a gradually extending deposit of carbon, which will then thicken in the usual manner.

(5) *Cruto's* conductor is obtained by means of a fine platinum wire heated to incandescence in hydro-carbon to obtain a graphitic deposit. Some say that the platinum is afterwards got rid of, leaving a carbon cylinder; but it appears that the platinum remains imbedded in the carbon, and that the varying resistance due to the heating is a compound of the rise due to platinum, and the fall due to carbon: high efficiency is claimed for this lamp.

1060. EFFICIENCY *of Incandescent Lamps.*—A clear distinction should be drawn between the *efficiency* of different lamps, and the *cost* of the light from them. The *efficiency* relates only to the *quantity of energy consumed per candle-power produced.* The *cost* depends upon this multiplied by the *cost of the energy* as delivered to the source of light. Efficiency is commonly stated in two ways, (1) as the joulads (in this case usually called volt-ampères) expended per candle-power; (2) as the number of candles developed per horse-power of the engine. The latter, while useful in considering cost, is not scientifically correct, because it includes the efficiency of the dynamo machine as well as the lamps.

1061. This expression of *light per H.P.* is, however, useful from the striking illustration it furnishes of the different light-producing effects of combustion and electricity. In §§ 921–4 it has been shown that 21 feet of gas will develop 1 H.P. in a gas engine: this gas at 16 candle-power will represent 67·2 candle-hours of light. This engine driving a dynamo would work 12 lamps of 16 candles or give, say, 200 candles of light. Therefore *the light-giving efficiency of the electric system is threefold that of combustion in this case,* which is a fair comparison of similar lights. In an arc lamp 1200 candles might be obtained, or eighteenfold efficiency, but this would not be a reasonable comparison.

But if we compare *cost* the result would be very different: the 21 feet of gas would cost only its price, while to treble its yield of light by electricity would need the extra expense of the engine and dynamo with their necessary labour.

1062. *The energy expended per candle-power* in the light itself is the proper test of efficiency of the light source, and it may be well to use gas as a starting point. On the data of § 921, in 5 ÷ 16 feet of gas, giving 1 candle hour, we have energy corresponding to 512,023 joulads; but as the common expression is based on the volts and ampères required to maintain the light, this being divided by 3600 gives us 141·7 volt-ampères per candle-power for gas. The following table derived from Sir W. Siemens gives useful information as to different lamps, but a little trade discount must be allowed of course for the comparison with Edison A lamp, because that, like others, has been improved. It must be understood also that "elec. H.P." does not mean total engine power, but only that expended in the lamp itself.

	Siemens and Halske Lamps.						Edison A Lamp.
	New.			Earlier.			
	II.	IV.	VI.	II.	IV.	VI.	
Normal candles	12	16	26	12	16	26	16
Volts	100	100	100	102·1	101·4	101·7	100·4
Ampères	.41	55·	80·	·50	·72	1·15	71
Ohms (hot) ..	244	182	125·	204	141	88	141
Volt-ampères ..	40·05	55	80	51·5	72·6	116·9	71·5
„ per candle	3·34	3·44	3·08	4·29	4·54	4·49	4·47
Candles per elec. H.P.	210	206	221	165	157	153	159

Similar particulars as to other lamps will be found in § 1069, and it will be seen that 3·53 joulads per candle is very good work (though the Cruto lamp claims to work with about half this), that is to say, one-fortieth of the energy in the gas flame: but to mark the distinction between *efficiency and cost*, the cost per candle for gas would be as ·0000222 × 40 = ·000888 against ·001945 for distributed electricity, using the prices shown per 1000 joulads of each, as the basis of comparison.

1063. *Heat effect of lights.*—The incandescent lamps generate much less heat for equal light than any combustion process: in fact the ratio would be that of the relative energies in the lights but for the amount carried off *potential* in carbonic acid and water vapour: the actual result, by experiment, is that the incandescent lamp gives about one-tenth the heat of an equal gas-light.

1064. *The action on the atmosphere* is of even higher importance: no products whatever are generated by the incandescent lamp, so that the presence of even high illuminating power has no effect upon the health, nor upon books, pictures, &c.

1065. These are matters of great importance in lighting *public assemblies;* the presence of moisture and carbonic acid affects the sound-transmitting power of the air, and the row of foot-lights across the front of a stage sends up a screen of these gases: it is found that these affect the transmission of music, which is therefore more effective when a row of incandescent burners replaces the usual gas-jets.

A very striking illustration of these advantages was given at the Birmingham Musical Festival in September 1882, which was lighted by Messrs Winfield & Co. with 488 Swan lamps. The temperature was actually lower close under the roof than on the floor of the hall: the result was that the singers in the orchestra suffered no sort of inconvenience, and for the first time there was no case of fainting, while the organ was able to be employed for purposes otherwise impossible, as it remained in tune throughout the whole of its own compass as well as through each performance. This is readily understood when it is considered that the ordinary lighting of such a hall produces heat and products about equal to those resulting from a full audience; on the other hand, the heat in this case plays a part in the ventilation, which must, in its absence, be otherwise provided for.

1066. *Duration of the Lamps.*—This has been greatly increased as the manufacture has improved. At first they failed very quickly and gave way under any undue current. Not only has the quality of the carbon wire been improved and its tendency to vaporize reduced, but the proper limit for each type of lamp is better known, which according to Mr. Fox is a working temperature of 4000° Fahr. The "life of the lamp" has been raised from 800 working hours to 2000, and many attain the good old age of 3 and 4000, while it is said that an Edison lamp worked at Strasburg has withstood over 5000 hours of work.

1067. The *giving way of the carbon* is attended with some curious effects: they commonly break close to the junction with the platinum, which may be due to a mechanical stress consequent on expansion and contraction; it appears, however, that this fracture occurs generally at the + side, and less frequently with alternating currents, so that it is well to change the sides of the lamp at intervals. It is not yet certain whether the carbon is vaporized, and diffused through the globe, or whether it is dispersed radially as in the molecular bombardments set up in Mr. Crookes' beautiful experiments: the latter appears to be the case with the particles of copper and platinum occasionally detached. These show a line of protection afforded by the carbon, where no film is deposited on the glass; but no such effect is seen in the case of carbon which deposits in a uniform film having the properties noticed § 1011.

1068. Ratios of Light to Current and Energy.—Light is a function of temperature, but does not increase in the same ratio: temperature is a function of energy subject to specific molecular properties of matter, and energy is as the square of the current all other things remaining unchanged. The exact relation of the electric current to the light it can generate is not yet fully known, but is roughly formulated upon two systems. It is considered to vary as the *fourth power of the current* = C^4. Now this looks as though it varied as the square of the work of the current, but this is not the case. When the work or energy is taken into account, Dr. Voit finds that the light is nearly proportional to the cube of the work or energy, and the formula is given

$$L = a A^3 \qquad \text{or} \qquad L = a A + b A^2$$

in which A is the energy, and a is a constant representing the light equivalent of unit work, while b is another constant related to the particular lamp.

1069. *Such formulæ cannot possibly be true:* they are mere empirical expressions for the actions within a limited range. It is evident that the true law must be a falling curve analogous to those of magnetism, fig. 111, p. 527, and that this curve will be different in metals and in carbon because of the reverse order of resistance variation. The expression C^4 is moderately correct in carbon, because it results in such a falling curve, as the work expended per unit of C is steadily lowered by the reduced resistance of the carbon: on the other hand it would not be true for a platinum or iridium wire. More exact experiments are required to establish the true relations, but the following table exhibits the relations as found by experiments at Munich: the comparison between a Swan carbon-lamp and a Cruto or platinum carbon illustrates the different variation of resistance due to temperature.

1070. The Cost of Electric Lighting.—At the commencement of the revival of the subject most erroneous statements

RATIO OF LIGHT TO CURRENT AND WORK.

SWAN.—46 Volt Lamps.					CRUTO.—No. 2 Lamp.				
Candle-power.	E. Volts.	C. Ampères.	Volt-Ampères.	R. Ohms.	Candle-power.	E. Volts.	C. Ampères.	Volt-Ampères.	R. Ohms.
·5	26·	·73	19·	35·6	—	5·69	·160	0·9	35·6
·97	29·	·83	24·1	34·9	—	11·34	·294	3·3	38·5
1·6	30·3	·87	26·3	34·8	1·2	22·17	·539	11·9	41·1
3·39	34·8	1·01	35·6	34·5	2·3	25·52	·611	15·6	41·7
5·69	37·1	1·10	40·7	33·7	3·3	27·33	·644	17·6	42·5
8·40	39·9	1·19	47·5	33·6	4·4	29·05	·681	19·8	42·7
10·7	41·2	1·23	50·7	33·5	5·85	30·99	·710	22·0	43·5
15·2	43·8	1·31	57·4	33·4	7·2	32·29	·742	24·0	43·6
24·1	47·6	1·44	68·4	33·1	9·2	34·01	·772	26·3	44·0
33·6	51·2	1·56	79·8	32·8	11·8	35·78	·801	28·7	44·7
48·0	53·4	1·64	87·6	32·5	15·7	37·47	·817	30·5	45·8
56·0	55·0	1·72	94·6	32·0					
62·5	55·8	1·76	98·0	31·7					

were made as to this, which led to extravagant expectations on the part of the public, and stimulated unwise investments which have resulted in heavy losses. The basis of the error was the comparing together things having no relation: arc lamps giving 2000 candles light with gas-lights of 10 or 16 candles power.

It would be pure waste of time to consider the cost of *arc lighting*, because it varies with the conditions of each individual case: the only useful information would be a statement of what has been attained under several conditions, and this would be out of place in this work.

1071. Statements commonly made as to the *incandescent* lights are also misleading when different lamps are compared, because while all become more economical the higher they are forced, each one has its proper limit at which it will do best work, while working uninjured; a comparison of mere light per horse power is, therefore, worthless, except at that limit, because beyond that limit the lamp will be speedily destroyed. This is illustrated by the case of a single Maxim lamp which worked at 12 candles gave 136 candles per horse-power, at 49 gave 426, and at 98 candles gave 607 per horse-power. The Maxim lamp is in fact best adapted to large powers and these figures are illustrative of the law of increase of light explained § 1068.

Another point to be recognized is that *apparent* economy, as measured in volt-ampères, is greatest as the resistance of the lamp is increased; but on the other hand the cost of *production* of electric energy is greater *per volt-ampère* as the volts increase in ratio, while the cost of *transmission* increases with the ampère ratio, so that the cost per volt-ampère is to be taken into account in comparing different lamps.

1072. An important element in the question of cost is the time during which the light is to be employed. This does not count in the case of gas supplied by a meter; nor would it in the corresponding case of distributed electricity; but the interest on capital outlay, &c., and often even wages for attendance, will be the same for 500 hours a year as for 2000.

1073. This is one of those matters in which "a little knowledge is a dangerous thing." To attempt to give actual figures of estimated costs in the space at command would simply mislead the reader, so that it is better to refer him to works treating on the special subject, or still better to the people who actually undertake the work and can consider the details of each case. A fair idea of the probable cost will be given by the figures in §§ 922–4 and the remarks in § 1060–2.

1074. It is evident from those sections that when compared on equal terms, as in the case of incandescent lights, the cost of the electric light must be greater than that of gas and that there is no likelihood of its superseding gas, the cost of which will certainly be reduced as the residual products grow in utility and value, while it can also be reduced by means of carburetting processes, as in the albo-carbon lamp. In fact it has been a great mistake of those interested in electric lighting to claim cheapness; its true recommendation is in its superior qualities, considered §§ 1062–5, which will in many cases cause it to be preferred though its cost were double—as it really is.

1075. But for isolated places, such as country houses or villages, where gas cannot be cheaply made, the electric light may well be actually cheaper. The same applies to localities in which there is a natural source of power available, or in factories where there is already an engine with its attendants, and therefore the cost is merely that of the extra fuel consumed to develop the power, and the capital expenditure on the dynamo and fittings.

1076. FITTINGS.—It is needless to describe these: they are the subjects of many inventions, or at all events, patents; but they are really adaptations, to the specific purpose, of well-known means, either already described or obvious to any one skilled in the subject: they are merely forms of connections, commutators, &c., modelled on the ordinary gas fittings, while the supports, electroliers, &c., are rather matters of art than of science, and however suitable to a work on electric lighting, would be out of place here.

CHAPTER XIV.

MISCELLANEOUS.

1077. THE ELECTRIC TELEGRAPH.—This subject it is not necessary to go into at all, as it is cursorily sketched in every work on electricity, and practical knowledge can be given only by the technical works. It is essentially an application of principles fully explained throughout this work, and resolves itself into three distinct systems.

(1) *Indicatory*, such as that of the needle instruments, which are to all intents simply galvanometers.

(2) *Recording* or *Mechanical.*—Such are the Morse and the printing systems, as well as those alphabetical instruments which do not record, but make a temporary indication. All these are actuated by electro-magnets working or releasing clockwork. Some of these also work by sound, the taps of the electro-magnet answering to the contacts made.

(3) *Chemical.*—These work by electrolysis, producing coloured marks when current is passed to the electrodes, one of which is a revolving cylinder, the other a point, a sheet of paper moistened with the electrolyte being interposed and drawn between the cylinder and the style.

The telegraph system is, therefore, simply the effecting of common electric actions at a distance, and is wholly a matter of resistances, and delicacy of instruments fitted to work with small currents.

1078. *Duplex Telegraphy.*—This, the causing two messages to be transmitted by one wire in opposite directions at the same time, has only been practically effected within a recent period, though the principles involved were known long before. It depends upon a very careful balancing of resistances: the currents do not pass each other at all, but if signals are sent simultaneously the effect is that the receiving instruments are really worked by the batteries of their own station, not by that of the sending station.

The instrument is essentially an electro-magnet wound with two wires exactly as a differential galvanometer, and acting upon the same principles. In one circuit is connected the line wire, and to the other a resistance equal to that of the line. Currents sent into this instrument from its own end will therefore not actuate it, as they divide into two equal parts; but a current entering by the line will actuate it, for (1) the station itself is *not* sending a current; then the line current passes through one circuit to the junction and back through the other, through a double resistance, but with double power, and so works the instrument in the usual way. (2) The receiving station is also sending; then according to the direction of the currents, one of the two circuits contains an additional or an opposing electromotive force, and thus an extra portion of the current enters one of the circuits and thus actuates its own instrument. The two instruments at opposite ends of the line being alike, and the resistances properly balanced, it will be seen that the operator at A station always sends his signals into his own instrument, but these do not affect it unless B is also sending signals into it, and therefore each operator only sees upon his instrument the result of the signals transmitted by the other operator, although they may be actually produced by his own battery set in motion by himself. In the case of submarine cables, there is, besides the line-resistance, the temporary and vanishing resistance due to "Charge," § 804, and to work on the duplex system a similar condition must be produced in the secondary or home circuit. This is effected by using, with the resistance equal to that of the line, condensers equivalent to the charge the cable is capable of taking up.

Quadruplex telegraphy is effected on similar principles, by employing different electromotive forces and instruments arranged to be suitably actuated by only one of the currents transmitted; a low force being unable to pass through a very high resistance instrument, while a small current under high force, which will actuate this, is without effect upon an instrument arranged to work with a larger current.

1079. AUTOMATIC TRANSMITTERS.—There have been many forms of these patented, but all are modifications of that first introduced by Bain to work his chemical receiving instrument. In principle the transmitter and receiver are the same. In each a revolving drum or cylinder rotates under a metallic style; in the receiver these are separated and yet electrically connected by a paper moistened with an electrolyte which permits currents to pass, and by the change of colour produced, records the time during which current passes, and in this manner effects signals. In the transmitter a strip or sheet of paper is interposed, which is perforated at the proper times to permit the point to touch the cylinder, and allow the current to pass: thus the marks on the receiving paper correspond to those perforated in the transmitting paper. But by the same means any kind of receiving instrument can be worked, as all transmitting instruments depend upon the making and breaking contact in one or more circuits for different graduated intervals, and the paper can be arranged to effect this mechanically. In other cases a sheet of metal is used, either as a cylinder or in a flat form, and is written upon with an insulating varnish. The style traversing over this sheet in a succession of close lines produces upon a paper at the other end, moved with the same velocity, marks which reproduce the original writing or drawing.

The advantage of mechanical transmission is that while the preparation of the message takes, of course, much longer than the direct process, many such messages may be preparing at the same time. But the actual transmission along the wire is limited only by the capacity of the receiving apparatus to record the signals, so that one wire and set of receiving instruments will do the work of many worked by hand.

The process is also very valuable in many experiments where it is necessary to measure exactly the period or duration of any action, which records itself on a paper moving with a fixed velocity. Thus the relations of inducing and induced currents may be made visible upon papers travelling side by side, with styles connected to the primary circuit and the two ends of the secondary.

1080. Electric Organ.—In this the access of air to the several pipes or reeds is controlled by an electro-magnet attached to each, instead of by rods and levers actuated by the pressure on the keys. The keys themselves have no mechanical work to do; they are simply "breaks," and act by closing the circuit of a wire from each key to its corresponding electro-magnet. The work of the performer is therefore far less laborious, and his touch much lightened, while the keyboard, not forming a mechanical part of the instrument, can be placed in any convenient spot, or, in fact, at any distance whatever from the music-producing instrument.

If a chemical receiving instrument is arranged with a style and connecting wire for each key and stop of an organ, &c., and a broad strip of suitable paper passes under them, when the key is pressed down a mark is produced, which thus records exactly the kind and duration of every musical note produced. The keys of a pianoforte, and indeed of most instruments, can be similarly fitted so as to record, exactly as produced, the musical thoughts or experiments of the composer, or to exhibit to a teacher, if required, the progress and work of a pupil while practising.

1081. EDISON'S MOTOGRAPH.—This is a modification of Bain's chemical telegraph, based on the discovery that some liquids render the paper *slippery* when current passes: as this implies less resistance to a mechanical pull, therefore, this discovery enables motion and sound to be produced at a distance without the aid of electro-magnets or of any mechanism to be actuated by the current itself, as the motion of the drum is produced by mechanical means at the receiving station. Thus, if the style is mounted as a rocking lever, it is drawn forward by friction of the paper while no current passes, and springs back the instant one appears, so that it may actuate a relay, or strike a bell. Caustic potash in solution gives the best results.

Edison's loud telephone is based upon this action, and it was at one time imagined that an electromotive force was set up, as chalk cylinders moistened appeared to generate a current on being moved: the real cause of this, however, was the chemical action on the brass axis of the cylinder; the points pressing on the chalk surface were immediately "polarized" by a film of gas, which motion immediately removed, and permitted current to pass.

1082. ELECTRIC BELLS.—These have the great advantage over the old-fashioned house bells that their wires can be carried anywhere, and require nothing beyond support; on the other hand they need the maintenance of a battery, which is of necessity a continual expense, though small, and is very commonly a source of annoyance. Electric bells, in fact, very frequently fail to act, and it should be understood that this is entirely due to the want of proper adjustment of the means to the desired end. This involves three considerations: (1) the source of force, the battery; (2) the conducting wires; (3) the bell itself, and these are inter-related; they must be adjusted each to the other, not each considered as an independent matter.

1083. The *battery* should be one not needing much looking after and not liable to speedy exhaustion. Only small currents are required for a single bell, therefore small cells are suitable to one or two bells, but the size must be proportioned to the number of bells likely to be in action at once, and it is better to use large cells, where needed, rather than to use several small cells coupled as one. One battery properly adapted will supply a large demand on it, but in some cases it is better to have two or more independent batteries, so as to avoid long conducting wires. The battery may be placed anywhere out of the way, where not exposed to freezing and not liable to have its liquids speedily dried up; therefore it is best contained in a closed box of its own: great care should be taken also to prevent the cells from getting wet and setting up local circuits. The manganese cells are most commonly employed, and Bennett's iron cells are suitable: where a heavy call upon it is likely, some forms of the bichromate cells are also used, but in these there is of course a local action. The number of cells in series must be such as will, after being short circuited for a minute, still freely work a bell through the circuit, and it is wise to use a cell more than is required, rather than risk failure. Cells composed of a strip of carbon in a deep porous pot filled with granulated carbon, placed in a vessel which need not be so deep as the porous vessel, and charged with sal-ammoniac solution, only half filling the porous vessel, will serve for circuits on which there is not a heavy call, but as they must be exposed to the air, they will require occasional attention by supplying fresh water to compensate for evaporation.

1084. The *conductors* may generally be No. 20 wire, but larger is preferable. It is necessary for one of the wires to be perfectly insulated; it is better for them both to be so, in case of accident; but if one is perfect in this respect, the other may be a naked wire, led anywhere and stapled to the wall. But where it is intended to use telephones, which will certainly come into general use by and by, it is important to have the two wires side by side to avoid induction, and both insulated. A convenient wire for these purposes is made with a No. 20 covered wire; and a No. 18 bare wire placed side by side, and covered with cotton as one; this, being passed through melted ozokerit asphalte, is very fairly protected against damp, and may be secured to the plastered walls by staples. A better plan is to let into the plaster the zinc tubes used for bell wires and draw the conductors through this, and probably the most perfect plan, where convenient, is to carry such tubes straight up the walls into the roof, from each set of rooms, so that any desired connection can be made, at any time, by tacking wires along the rafters from tube to tube. In this way a complete system of bell and telephone communication could easily be arranged, and if desired, clocks, in the different rooms, could all be worked from one driving clock in the hall or elsewhere.

1085. Double wire is not always desirable for such a circuit, intended to include several instruments, as the wire may leave one pole of the battery and travel singly all through the circuit, returning to the other pole. In fact the circuit must be arranged to suit its purpose: and in such a house system as referred to, it would be unwise to attempt to make one circuit serve too many purposes: it would probably be better to provide a common "return" circuit of a stout wire, connected to the negative pole of all the batteries, if more than one were used, and then carry insulated wires, as required, to constitute the independent circuits. Those who have studied the principles explained in other parts of this book, will have no difficulty in doing this properly.

1086. An example or two may, however, assist some, and the connections of an annunciator system will serve the purpose. Let us suppose that from every room in a house it is desired to communicate with the kitchen. A single "return," or as it is commonly called "earth," wire should be connected to the zinc of the battery, and then either traverse all the rooms, or pass from floor to floor with branches from it into each room: a wire should connect the + pole of battery to one terminal of the bell in the kitchen; the other terminal would then be connected to the annunciator system by a wire which would there be separated into as many independent wires as there are signal-magnets, one terminal of each of these being permanently connected in this manner to the bell: now an independent wire from the other end of the proper signal-magnet to its own proper room will complete the system.

The magnet actuated from any room, releases an arm and allows a disk to drop which uncovers the name or number of the room and leaves it so until the attendant has seen it and by pulling a string returned it to its place, when it is held up by a catch attached to the armature.

1087. The bell itself is subject to one principle of construction, it requires a specific amount of mechanical energy, which will depend on the volume of sound desired, and on the strength of the spring and the magnet which strikes the blow, § 950. The electro-magnet requires to be so proportioned as to supply this energy. Now this involves the adjustment of its wire to the battery: the energy may be obtained by a stout wire with few turns, acted on by a battery giving a sufficient current with a low E M F, that is from one cell, or it may be derived from a fine wire of many turns, receiving a small current from a battery capable of forcing it through the circuit. People who do not understand the principles appear to expect that any battery is to work any bell, and if it does not, they complain of imperfection and failure; but the failure is in their not properly adjusting the means to the end.

1088. Electric bells are made on two principles, *single stroke* and *vibrating*, and they are made and sold so cheaply that they will hardly pay any one to make for themselves. The simplest construction, for a bell to hang against a wall, consists of a piece of wood with a pillar and screw to carry the bell: beyond this the horse-shoe magnet may be attached, by means of a block of wood glued on the base, so as to go between the arms, and a thin piece of wood crossing the magnet and tightened down upon it by a wood-screw. A metal stem just beyond the magnet carries a spring to which the armature is attached, adjusted so as to play over the required space to give the stroke. The hammer is carried on a strip of elastic metal attached to the armature, and so adjusted that when at rest against the magnet the hammer is just clear of the bell: the actual blow is given sharply, by the momentum given to the hammer overcoming the spring of its support. The distinction between the two kinds of bell commences here.

(1) *A single stroke bell* acts by the connections to the two circuit wires being made direct to the two ends of the electro-magnet wire. The stroke is made as often as required by the person actuating the bell.

(2) *A vibrating bell* has a break similar to that of an induction coil, § 963. The circuit is made from one wire to one end of the magnet-wire, the other end of which is attached to the pillar which carries the armature. The other circuit wire is connected to another pillar carrying a spring, the end of which carries a platinum point facing a piece of platinum on the armature, the distances being so adjusted as to produce the desired rate of vibration and length of stroke; the object of the spring is to maintain the contact long enough to secure the full magnetism being attained. These bells continue striking as long as the circuit is closed at the other end.

1089. *Pushes* are contact makers, which may be of any convenient construction. The ornamental ones made for sale consist of a piece of hard sheet metal which is cut into a spiral with a plate in the middle, which when pressed down, touches a plate to which one wire is attached while the other is attached to the spiral itself: a loose plug rests on the outer side of the plate and passes through a hole in the cap which screws down on the base, after it is fixed in its place by screws passing through it, and holds all in position.

1090. *Two pieces of metal* insulated from each other, may act by being pressed together at their ends, and this is the best *self-acting circuit-closer* that can be fitted to doors and windows to ring when they are opened or shut as desired, according to the position in which they are placed, being let into the wood with the one plate projecting sufficient for the purpose: thus, at a door, if to ring when shut, they should be let into the stop against which it closes, or behind the back of the door; if to ring when opened, they should be over it and standing out, with the outer end prolonged and turned back so as to receive the door again as it closes.

1091. *To protect a whole house*, such a pair should be fitted to every desired point, with a battery and bell in the spot where the alarm is desired, and a switch to turn it off when not required. The resistance should be large and the alarm made accordingly, because a constant current will be passing; the alarm should not ring the bell itself but act as a *relay;* that is, its armature should be held to the magnet, and when not so held will close a circuit from the battery to the bell by springing back against a stop. Now when the place is shut up, the observer will turn his switch on, and if all is right, the armature will be at once drawn up to the magnet, and then the bell can be turned on, unless the switch is made to close the two circuits at one action. If by any negligence any place is left unfastened, the bell will ring and give warning, and will do so at any time should a door or window be opened. Of course by the more complex system of § 1086 the apparatus would at once indicate at what point to look for the defect, or a local alarm would also act.

1092. *Switches* are instruments for directing current to one of several instruments. For experimental purposes, nothing is better than a piece of wood with a hole in the middle, and a ring of equidistant holes to contain mercury: a bent wire connects the required hole to the circuit, wires from each instrument may dip in the separate cups: such a switch is shown on Fig. 56, p. 208. A more elaborate instrument may be made of a block of wood, with a pair of binding-screws for each instrument, and a pair for the battery; one of these last is connected to one of each of the other pairs; the other battery screw is connected to the central point; this may be a pillar with a spring traversing a series of blocks connected each to its proper screw, or it may be a block of brass surrounded with a ring of segments as described § 399, Fig. 58. An efficient rough instrument can be made with round headed brass screws, the central point being a similar screw passing through two brass washers with the spring between them; the leading wires can be soldered to the screws on the under side, or to plates of copper either below or on the face, to which the screws make contact.

1093. *Compound Switches.*—Where it is required to be able to connect any one of several circuits to any one of several others (as of course is done in telephonic exchanges), a flexible conductor with a plug at each end can be used; for a moderate number, the simplest plan is to arrange a set of metal strips on a board, with a second set crossing them, but not in contact; holes are bored at each crossing so that a split plug can be passed through and make connection.

1094. TELEPHONY.—Until very recent times it was believed that the production of articulate speech required a complex organism; yet every echo taught the contrary. However, until speech actually issued from the diaphragm of the telephone, people overlooked the certain fact, that every sound whatever, in crossing space, is resolved into *vibrations of the air*, and that the production of sound, musical or articulate, only requires an initial motion which can set up those vibrations. An echo is due to a surface which receives and reflects or reproduces vibrations in the air. If we hold a sheet of stiff paper in the hand we feel it trembling in answer to any sound, and those tremblings, if analysed, represent the sound, and if properly applied will reproduce it.

A strained diaphragm such as a tambourine, answers even more perfectly than the sheet of paper, and proves that articulate speech can be produced by a mechanical vibration. It can even translate the vibration into a visible record, which was done by Young in 1807.

1095. Scott's *Phonautograph* is the best known instrument for the purpose; it is a large cone to collect the sound, with a diaphragm across its base; to the middle of this diaphragm is attached a point which rests lightly against a cylinder covered with a layer of smoke, which being turned, records the sound in a series of undulating marks; each sound having its own specific form.

The *string telephone* carries the principle one stage further. Though introduced as a common toy since the discovery of the electric telephone, it long antedates it in practical use; unknown to science, it had been invented ages ago by the Chinese, was used by the natives of Ceylon, and had even been employed by English schoolboys for purposes of surreptitious intercommunication.

It consists simply of the tambourine connected by a strained string to another tambourine, each fitted with the cone of the phonautograph: it is, in fact, a phonautograph which instead of moving a point and tracing a line, moves a string, and through it a second reversed phonautograph, which reproduces the original sounds.

1096. *Edison's Phonograph* carries us another stage; it is the phonautograph again, but the smoked cylinder is replaced by a groove covered with tin foil which records the motion of the style of the vibrating diaphragm, in waves, not only in one direction, as a sinuous line, but in all directions, as a waving groove. Like the string telephone it sets a second diaphragm in motion (or its own) by the point actuated by this groove; consequently it is able to effect this reproduction, not at the moment, but at any time and as often as is required, provided means are employed to transform the soft tin foil into a more enduring substance.

1097. *The construction of the phonograph* is very simple in principle, but requires the utmost care and accuracy of workmanship to secure satisfactory results: it consists of a cylinder of brass about 4½ inches in diameter, and of length to suit requirements; this is mounted upon an axis prolonged on each side more than the length of the cylinder, to work in bearings twice the length of the cylinder apart: one end of the axis and its bearing are made as usual in machinery, while the other is a perfectly true screw working in a nut, so that when the cylinder is rotated by a handle on one end, it traverses the space between the bearings. A corresponding groove is cut in the face of the cylinder which should form a square thread, not a conical one, and the threads should be from 8 to 14 to the inch, with a depth of about 1-20th of an inch. The cylinder is covered very smoothly with a sheet of best tin-foil of about 1 ounce per square foot.

Two diaphragms are best; one like that of the ordinary telephone, made of ferrotype plate for receiving, and the other of tough paper, preferably parchmentized, from which the sound is reproduced with less injury to the foil than from an iron plate; as these diaphragms must be movable in order to give access to the cylinder, they should be mounted upon hinged frames so as to fall back, and provided with a means of exact adjustment as to pressure on the foil. The simplest construction is to fix a foot to an upright board forming an L section; in the upright part the mouth-piece is mounted, and the diaphragm is secured upon a circular moulding, with a screw cap, or in any other convenient mode, so as to act as the telephone receiver does. The foot is hinged at its further edge to a similar, but longer strip of wood, which latter can be screwed to the base board at its projecting ends, when the position of the diaphragm is exactly adjusted to the grooves of the cylinder: a pair of springs, either of steel strip or spirals inserted in holes in the lower strip, should be used to press the frame backward: a slot should be cut across the middle of the base of the frame, and through this there should rise an iron rod with a screw cut on its end, and carrying a *button*, such as is used to fasten doors, but prolonged as a handle at one side, which will pass freely through the slot when turned in that direction; when turned across the slot it will press the frame forward against the action of the springs, and so adjust the distance of the point and foil: to aid the adjustment, the sides of the slot should be formed with a slight slope, and the button be held in place by a spiral spring round the rod to press it upwards while a nut on the screw will adjust its exact position: then to obtain access to the cylinder it is only necessary to turn the buttons and let the diaphragm frames fall outwards. The receiving diaphragm is made of a ferrotype plate as in the telephone, but has a steel point attached to its centre; this point may be made from a hard darning needle, and must be so ground as to have a fine smooth point, not sharp enough to *scratch* the foil: about half an inch being broken off, it should be held in a pair of pliers, the back end moistened with soldering flux, and tinned by rubbing on a piece of sheet tin with some solder on it held over a Bunsen's burner, or upon a hot soldering iron. The plate should have a small spot cleaned at its centre, and being then supported over a Bunsen burner or a spirit-lamp, at a distance such as will not burn the varnish, but will heat the plate equally without causing it to buckle, a small piece of solder on the spot will melt, and the point being carefully applied should be placed perfectly upright, and the heat being removed the two will be firmly soldered together.

1098. *The speaking diaphragm* is mounted in the same way, but is on the outer side of the frame; it can be most conveniently fixed like the parchment of a drum, by being moistened, laid over the circular rim arranged to carry it, and then firmly pressed on by a close fitting brass ring, upon which again may be fitted the paper cone which is used to concentrate the sound. The point is not attached to the diaphragm, but is carried by a strip of spring steel or brass screwed to the top of the frame, and it actuates the diaphragm by passing through a loop of silk thread of the proper length which is attached to the middle of the diaphragm by a small square of court-plaister or other simple means so that the spring keeps a slight strain on the diaphragm.

1099. The points should be adjusted so as to touch the foil a little beyond the axis of rotation, and so as to slightly indent the foil when at rest, and the frame which is not in use should be turned out of contact. One diaphragm is used for both purposes, but as Mr. Shelford Bidwell (on whose instrument described in the *English Mechanic*, 26th April, 1878, the foregoing description is principally based) says, the result is not so satisfactory as with a pair adapted to the different purposes.

1100. *A flat plate with a spiral groove* has been employed, and would have an advantage for many reproductions because a stereotype could easily be taken from it in hard metal which would be nearly indestructible, or of which many copies could easily be produced. This would greatly add to the value of the instrument, which so far has disappointed expectation by not being applied to any practical purposes. It would appear that as an agency collects news and even sends out stereotyped leading articles and other matter for several papers, so we might be able to enjoy the eloquence of favourite speakers at any time and place: or a good phonograph might advantageously replace preachers who employ printed sermons, so as to furnish a good delivery and expression as well as ideas, just as the barrel-organ distributes popular music. At all events it might proclaim intelligibly, on railway platforms, the various information and directions with which the porters now puzzle the traveller. One practical use has been recently devised in recording the speech of distant savage races for examination at leisure by philological experts.

1101. THE TELEPHONE.—This instrument has come into practical use almost from the day of its first real introduction, and unlike most inventions was perfected at once: but this only applies to the actual instrument—to Bell's telephone, which notwithstanding numerous claimants to improvement, remains the best for general use. It is not intended here to enter into an examination of the various claims to the origination of the telephone beyond the remark that it is pretty clear that Reiss fully conceived the idea, and made a working apparatus which, if not perfect, only required a little use to make it so; but his idea remained fruitless, though it may probably have been the germ from which the later successful instrument was derived. There are many people who, doing little themselves for the world, appear to find a pleasure in fancying they diminish the credit of a successful worker, by pointing out that some one had anticipated him, and the vaguest intimation of the possibility of something being done, is quite enough for these people. On the other hand, an idea once published and become as it were public property, becomes a seed which germinates in another mind, and that mind perfects it, possibly without an idea as to whence the fertile suggestion was derived, and without this origin in the least diminishing the merit of the person who has ultimately brought the idea to completion.

1102. It is right to recognize the fact that Reiss really brought the telephone near perfection, and Prof. Syl. Thompson has done good work in demonstrating the fact; nor is it unlikely that the work of Reiss directly or indirectly influenced the mind of many people, and among them that of Bell while working out the subject. But we must recognize that Bell *did work it out*, and is its legitimate inventor. Equally certain is it that the completion of the practical system of telephony is due to Prof. Hughes, whose microphone, *freely given to the world*, is the basis of the numerous patents and so-called inventions for the transmitting part of the system. Quite recently a new claimant comes forward, a Mr. Drawbaugh, who professes to have discovered the telephone before Bell. But whatever the American patent office may decide, and however such a claim may operate on the market price of telephone stock, from a scientific point of view it is impossible to attach any importance to an invention of which no one heard anything till several years after its subject had been successfully used all over the world: a "caveat" may entitle a man to legal priority of invention; but publication and giving to the world is the only title in the courts of science.

1103. *Gray's Harmonic Telegraph*, and other similar inventions, were a natural starting-point; they transmitted musical notes, and many important uses could be made of them which space will not allow us to enter upon; but musical notes and articulate speech have a fundamental distinction. Musical notes, § 983, may be produced by an even succession of independent impulses, as in the *siren;* in fact a card drawn along the teeth of a fine saw will produce a note varying with the rate at which it is drawn: therefore an electro-magnet armature would reproduce such notes at a distance. But the production of speech requires a current not broken, but varying in quantity, or what is called an *undulatory* current: to produce this, the circuit must not be broken altogether, but one of two variations may be employed.

(1) The acting *electromotive force* may be varied.
(2) The *resistance* of the circuit may be varied.

The first is the principle of the Bell telephone used as a transmitter: the second is the principle of the microphone and its derivatives.

1104. The *fundamental facts* underlying the telephone are those studied §§ 456 and 969.

(1) When a piece of iron is moved in a magnetic field, it disturbs the molecular magnetic balance of the magnet on which that field depends: in other words, the approach of a piece of iron to a permanent magnet causes a change in the internal molecular constitution of the magnet itself.

(2) When this magnetic balance is disturbed, an E M F is set up in a wire coil surrounding the magnet, which will produce a current.

(3) When a current is produced in such a coil by an external E M F it affects the molecular constitution of the contained magnet, and also modifies the whole field.

1105. The *first and typical* telephone system consisted of two such similar magnets whose armature was a flexible iron disc: the impulses of the sound waves move the receiving disc; the motion varies the magnetism, sets up a rising and falling E M F, and sends an undulating current to the second or speaking telephone. Here the same phenomena are produced in a reverse order, and it was at first supposed that the sound was produced by a mechanical undulation of the second disc corresponding to that of the first, that this disc in fact moved as an armature under the varying strength of its magnet. The real action is much more complex, and will be studied § 1112.

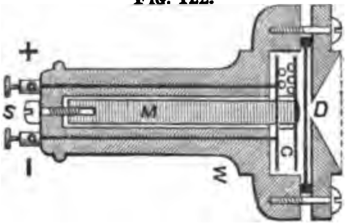
1106. The *currents of the telephone* are exceedingly small because they are related to the energy expended upon the disc in vibration, § 576, and this distributed over a circuit of considerable resistance: an ordinary galvanometer will not show them because they are of necessity alternating from instant to instant: but their existence may be proved upon a delicate galvanometer by lightly pressing the disc, when a current in one direction will be shown, reversed when the pressure is removed: it has been estimated that currents of a ten-millionth of an ampère will give audible sounds. One consequence of the exceeding smallness of the acting E M F is that even imperfect insulation will not destroy the action, for telephones have been worked by naked wires lying on the ground. The two lines of a railroad have even been used as the circuit for a distance of several miles.

1107. *Battery Currents* were at first employed by Prof. Bell, as by all his predecessors, to actuate electro-magnets forming part of the circuit, while a "polarized armature," i. e. a permanent magnet attached to the vibrating diaphragm, by its motions varied the magnetic intensity of the electro magnet, and by its reaction altered the rate of current passing, which therefore became an undulating current.

1108. The next step, a simple and natural one when it was found how small a current would suffice, was to cut out the battery and interchange the core and armature, using a permanent magnet core, whose magnetic intensity was varied by the motion of the soft iron armature, which, being a disc of much greater diameter, collects the lines of force from the other pole of the bar. This idea appears to have occurred to Prof. Dolbear about the same time as to Prof. Bell. But as a matter of principle the difference is slight; it is merely a matter of convenience and expenditure, and the introduction of the microphone, which requires an external current, has made the use of electro or permanent magnets a matter of indifference, except as to the relative importance of cost and the greater power of the electro-magnet. The regular current passing plays no part in transmission, it simply magnetizes the core; it is the *variation* of the current which does the required work, and the undulating current derived from the permanent magnet is the equivalent of that variation.

1109. CONSTRUCTION.—This will be understood by aid of Fig. 122; the magnet M is a rod of good steel highly magnetized, it may be 4½ inches long by ⅜ in. diam. It is often terminated by an end of soft iron to enter the bobbin, as this has higher capacity for magnetic variations, § 945. It fits in the central tube of the wooden casing W, and is provided with a screw S to adjust its distance from the diaphragm D. On the end of the bar is placed the reel C, which may be 1⅛ inch in diam. with a space of ⅜ inch, to contain the wire, the size of which should be adapted to the resistance of the circuit, 35 gauge being the most generally useful: the ends of the iron are carried down through holes in the wood to the terminal screws + and −.

FIG. 122.



1110. The *diaphragm or disc* is usually made of ferrotype plate cut to a 2-inch circle, with great care not to buckle or distort it in any way; it should be held by a narrow circle of india-rubber or soft paper above and below it, to deaden the natural vibration of the plate as a whole, which would harden the sounds and give prominence to any vibration corresponding to itself, § 984.

The *mouth-piece* is a cap with a conical space ending in an opening of half an inch, so as to collect the sound waves and deliver them direct upon the centre of the disc.

1111. The *spaces between the disc* and the opposing surfaces should be no greater than just sufficient for the play of the diaphragm; this obviates the disturbance by resonance in the upper space and facilitates induction between the disc and the wire, which appears to play an important part in the action, § 1115. For this reason the slightly rounded end of the bar should only just project beyond the bobbin and should be brought as near to the disc as is sufficient to avoid any contact: this adjustment is best effected while a note is sounded in the instrument from an automatic break, so as to perceive the exact point at which the best result is obtained.

1112. ACTION OF THE TELEPHONE.—That the speaking disc should vibrate, like the receiving disc, is naturally to be expected; that such an action does occur is proved by an interesting experiment of Prof. Dolbear. He coupled two telegraph sounders in different rooms, then attached the cord of a string telephone to the armature of one, so as to move it mechanically when spoken to: the other sounder responded freely to musical notes and partially to speech; later experimenters have also found that a common electric bell, or rather its magnet and armature, will reproduce sounds if so adjusted on an elastic spring as not to quite break contact.

But it has been denied that the sound is thus produced: the vibrations of the speaking diaphragm are so minute as not only to be incapable of mechanical measurement, but they are not even visible by reflection of light; they can, however, be proved to exist by making the diaphragm serve as one of the supports of a rod of carbon fitted as a microphone; this will then reproduce the original sounds, proving the variation of pressure, while the apparatus constitutes a telephonic relay which may yet have its uses.

1113. *The amplitude of a sound vibration* may really be inappreciably small, when the sound itself is feeble, as in those of ordinary telephones: in fact, it has been calculated that an amplitude of 400 millionths of an inch may suffice; it is also known that a bar of iron lengthens in magnetizing, according to Joule 1–27000th of its length; so that not only would the bar lengthen and shorten, but in so doing it would add this effect of approximation to that due to the magnetic increase, and so produce a motion of the disc which, while ample according to the foregoing figures to produce a sound, would yet be far below the limit of visibility or measurement.

It has been argued that a molecular increase and decrease in the thickness of the disc itself is the source of sound, and thin as the disc is, the proportions would be adequate.

1114. *Iron in magnetizing and demagnetizing* gives out a sharp "click" to which the action is sometimes attributed, but interesting as the fact is, as an evidence that some actual motion occurs in magnetizing, which, if frequently repeated, even heats the metal, yet it appears unlikely that the undulating currents of telephony would produce that motion so suddenly as to generate sound.

1115. We know that *inductive or static charges* set up actual attractions as used in the balance electrometer, § 64, and that such charges are produced by and vary with electric currents, § 803, and that these charges and changes imply some action, involving motion in the particles of air between the two surfaces. There is good reason to suppose that this plays a part in the action, for there must be induced charges between the wire coil and the metallic disc, which collects in itself the lines of force. In fact telephones have been devised which depend on this action alone, § 1123–4.

1116. The *thin iron diaphragm* may therefore be replaced, in some forms of telephone, by thick plates, or other metals and even non-metallic substances. The *iron core* even may be dispensed with. Sounds may even be received from a single plate of any metal connected to one conductor, and held by an insulating handle: in this case it is obvious that the action is purely one in the air between the insulated plate and the surface of the face, which forms the other electrode through the earth circuit. In fact, this is an elementary type of Dolbear's induction telephone, § 1124.

1117. *Horse-shoe magnets* are employed, instead of bars, upon two principles: (1) allowing the two poles, each with its bobbin, to act upon one disc, made elliptical; (2) so forming the magnet that the second arm shall induce magnetism in the disc so as to concentrate the lines of force into the space between it and the acting pole.

1118. *Edison's receiver* is derived from his motograph, § 1081: a cylinder of moistened chalk receives the currents and transmits them to a movable platinum point which is attached to a diaphragm: on rotating the cylinder this point slides more or less freely as the current varies, and so actuates the diaphragm as to reproduce the sounds with an intensity sufficient to be heard in a large room; because, as indicated § 1081, the mechanical energy has not to be transmitted, as in other telephones, from the point of origin, but is supplied at the receiving end.

1119. *Edison's transmitter* produces an undulating current by varying the resistance: this is effected by pressure exerted by the diaphragm upon a block of carbon composed of compressed lampblack. Mr. Edison claimed the discovery of this change-able resistance as made by him in 1873 and utilized in producing rheostats acting by varying pressure upon powdered carbon in glass tubes. There is no reason to doubt the actual discovery, but, like many other supposed inventions, the fact itself was public property, having been published by Du Moncel in 1856, and rheostats were made on this principle in Germany in 1865. But the fact has been very usefully applied by Mr. Edison not only in telephony, but in other delicate instruments, such as the micro-tasimeter.

The external form is similar to the Bell telephone, for convenience of holding, but the movable rod which replaces the magnet is only of use for adjusting the initial pressure: on this is laid a platinum plate connected to the circuit, then the block of compressed carbon, covered by another platinum electrode, and a plate of ivory or glass: in the middle of this a brass cylinder (which replaces an india-rubber block at first used) transmits the motions of the diaphragm, or the varying pressures due to the impact of the sonorous waves when a more solid or non-vibrating plate is used.

1120. *Transmitters in which the resistance varies* permit the use of induction coils: adapted either to sending currents through large resistances, or of working telephonic condensers by charge. The transmitter replaces the contact break and sends undulatory currents from a battery into the primary of the coil, while exactly similar undulations are produced in the secondary wire: these however have a much higher E M F than those of the battery, and are adapted either to sending currents through a high resistance, or to working condenser telephones by "charge."

1121. A simple form of transmitter which effects the same actions, while really based on different principles, may be made with a piece of wood on which a plate of metal is laid for the electrode, on this is placed a piece of thick soft felt, such as is used in pianos or for corn-plasters, and perforated, as in those plasters, with 3-8ths inch holes all over its surface; these holes are packed with small fragments of graphite and then the felt is covered with a piece of tinsel foil serving as the second electrode; a piece of wood with a hole in its centre is laid on and pressed down by screws passing to the other wood, of course clear of the metals. The loose tinsel replaces the vibrating diaphragm, and under the varying pressures of the sound-waves it bends over the pieces of graphite and makes more or less of surface contact, both of its own surfaces and among the various fragments; in fact, it acts just as the microphone does.

1122. *Reiss's original transmitter* is a close approximation to the microphone: it consists of a light balanced lever, one end resting against the diaphragm, the other closing a contact, which if made against an elastic face would produce varying pressures rather than actual break of circuit, or might introduce a mere film of air, remaining a conductor as in the arc.

The microphone takes, in fact, just that slight step by providing contacts which vary in number and pressure, and therefore in conducting capacity.

1123. *Varley's Condenser.*—This consists of an ordinary condenser made of a number of sheets of tin foil separated by double sheets of thin paper coated with shellac varnish; the sound is produced by the actual motion of the foils and papers, resulting from the successive attractions, together probably with undulations of the contained air. It was patented April 1870, and was mainly intended to assist in multiple telegraphy, the working out of which was in fact the object of the other telephone inventors.

1124. Prof. Dolbear carried the idea a step further by producing a telephone consisting of a simple air-condenser composed merely of two plates close to each other, each connected to one terminal of the circuit: its action depends on the principles explained § 1116: as it requires a high E M F to work it, such as is derived from the induction coil, it is less subject to disturbance by surrounding actions, which are usually at a low E M F.

1125. Mr. Preece has shown that the varying temperature and consequent expansion and contraction produced in a wire carrying the current will reproduce sounds: he found platinum wire of ·001 inch, 6 inches long, stretched between a pillar and a diaphragm, to give the best results.

1126. The attractions between the turns of a helix, § 964, either with or without an enclosed magnet, have also been proposed to vibrate a diaphragm, as also have been the polar attractions of the two arms of an elastic horseshoe magnet.

1127. If a bar of soft iron be hammered out flat for about half its length, sufficiently thin to vibrate pretty freely, and then bent first at right angles where it begins to thin, and curved over itself as a swan's neck, and a coil of iron be applied under the first bend, an intermittent current produces vibrations of the thin end, although the magnetic polarities are the same at the bend and its opposing end: this is because the return lines of force are greater in one case than the other, and also because the change of magnetism occurs more rapidly close to the coil than at the ends, so that for a moment there is a difference of polarity generated. Such an apparatus acts as a telephone if a disc of cork is adjusted to the vibrating end.

1128. The great difficulty of the telephone is that its extreme sensitiveness reveals electric variations inappreciable by any other means. It testifies to the slightest changes of magnetic intensity, or of electric current anywhere in its neighbourhood. This faculty is utilized in the induction balance, § 1166 and in replacing the galvanometer in the Wheatstone Bridge, and in testing changes as suggested § 840: in like manner it proves that the currents from dynamo machines are not absolutely constant, and shows the intermittence of the action of the Holz and similar machines, and of vacuum tubes when the striæ are manifested even from a battery, such as described § 101. For such purposes two suitable circuits are wound parallel, or an induction coil with break screwed down can be used.

1129. TELEPHONE CIRCUIT.—As a consequence, the telephone is subject to numerous disturbances. The receiving disc may be disturbed by surrounding sounds or mechanical vibrations, as well as by the speech directed to it, but this may be guarded against. The varying currents passing in neighbouring wires will *induce* currents in the telephone circuit, and some very extraordinary instances of this are on record. The only sure protection against this is to use double wires of the same dimensions for the circuit, and these ought really to be twisted up as a cord, to ensure equal distance of the two wires from all surroundings. The rapacity of make-believe inventors has been fully exercised in this matter, and the most obvious expedients, such as would occur to anyone, have been coolly patented; even the mere use of a return wire circuit, instead of the "earth," was patented, and possibly the patent was sold, although this is the ordinary mode of forming an electric circuit, and the earth return is a mere matter of economy. It is doubtful whether patents are valid when claiming such public property, merely because it can be obviously applied to some new use, new only because the subject may be new, as in telephony; but it is not doubtful that they ought not to be valid.

1130. THE MICROPHONE.—If two wires, forming part of a circuit with a battery and a galvanometer, be simply laid across each other, a current will be seen to pass: if pressure is applied to the crossing, this current will be seen to increase. It is said that pressure diminishes the resistance, but the intelligible explanation is, that it increases the conducting capacity, by slightly flattening the wires and enlarging the actual surfaces in contact. This is the principle of the "Microphone." Prof. Hughes observed that the vibrations due to sound-waves were sufficient to produce this varying conductive capacity, and devised an apparatus for applying the vibrations, which being influenced by almost infinitesimal vibrations, and manifesting them as comparatively loud sounds, he called the *microphone*. This instrument he gave to the world, and it is the foundation of most of the patented transmitters now in use.

1131. In fact, the form and arrangement may be varied almost *ad infinitum*, as may the materials, though it is found that carbon is the most advantageous in practice. The simplest and earliest experimental apparatus consisted of two nails with a coin lying over them: if we place a finger on the top of a table, and then speak to the table, we shall feel a vibration due to the impact of the sound-waves, and this is sufficient to produce a varying contact between the coin and nails; substitute for the table a better resonator or sound-board, or elastic diaphragm, and for the nails and coin, pieces of carbon in variable juxtaposition, and we have the microphone, which as at first stated, to the surprise of the world, would make the "tramp of a fly" audible at a distance. In fact, it has been said, with scientific truth, that a fly, when it settles, shakes the world: that shake is however not appreciable, but each footstep of the fly will certainly vibrate a sensitive sound-board, and what is heard in the telephone is not the footstep of the fly, but a wholly new sound, the mechanical equivalent, not of the work done by the fly, but of a disturbance in an electric circuit in which strong forces may operate.

1132. *The most sensitive form* consists of a vertical sound-board or diaphragm on which are secured two blocks of carbon connected to the circuit: in each of these a small conical hole is formed to receive the conical ends of a light stick of carbon. The *cup and ball* transmitter of Mr. Strangways is a modified form of this: he takes the upper part of a telephone as in Fig. 122, and replaces the magnet and coil by a block of carbon with a deep cone formed in it; a similar block is attached to the lower face of the disc, and a sphere of carbon, like a pea, is placed between; then the angle is adjusted so that this pea makes contact between the two carbons, by lying across the joint, and the motion of the disc, when spoken to, varies the surface in contact.

In fact, it is better in all cases to attach only one terminal block to the vibrating surface and the other to a fixed point capable of adjustment, or to a spring or weight independent of the sound.

Edison's transmitter, § 1119, is really actuated in the same manner as these forms of microphone, though Mr. Edison himself at first thought an actual variation of conductivity occurs; but it is now known that the effect in all cases is due to a more or less perfect, or greater or less surface of contact.

1133. THEORIES OF MICROPHONE ACTION.—There has been much discussion on this, and several explanations are maintained; as (1) a variable resistance due to compression of the carbon itself—this is now entirely disproved; (2) variation due to alteration of the number of molecules, or area of surface in actual contact; (3) variation due to pressure of air film preventing absolute contact, but itself acting as a conductor; (4) the formation of a varying *arc* of varying resistance, in such an air film; (5) an intermittent and complete make and break of circuit. The last two may appear alike, but there is an essential difference of principle between them, dependent upon whether the circuit is actually broken and current stopped, or whether there is merely a rise and fall of conducting capacity, never interrupted, with a consequent undulating current.

1134. The *air film* theory, and that of *actual contact* differ, and yet agree, for the question arises, *What is actual contact* in this aspect? All surfaces have a film of air (§ 642) on their surfaces, while carbon possesses special powers of condensing gases. Microscopic examination tends to show that there is a slight separation, and even a repellent action, and Mr. Stroh has estimated that a space of 1-2000th of a millimetre exists, at all events in a delicately balanced microphone: it seems improbable that such can be the case where, as in the Edison and Blake transmitters, a considerable initial pressure exists. Messrs. Probert and Soward appear to have proved, in a paper read April 12th, 1883, to the Society of Telegraph Engineers, that this film does exist, for they arranged a microphone contact in a vessel through which they passed streams of different gases and found a difference of resistance, viz. moist air 386 ohms; dry air 520: carbonic acid 435, and hydrogen 600, with corresponding effects in reproducing sounds.

1135. *But such minute films are conductors*: that is to say, electric transmission takes place across them just as it does through a moderately good conductor of high specific resistance, though this may be for air, greater than that of carbon, as this is greater than that of silver, p. 283: or it may be simply a question as to the distance at which the molecular actions can occur, and produce electric transmission. But we know that such films do not arrest electric transmission, for even the very low E M F employed in electro-metallurgy surmounts them. A piece of gold fresh cleaned receives an adherent coating of copper; but if we leave it exposed to the air to reform its film, we can at once deposit copper on it freely, but the coat will not adhere, § 642: we have here the distinction between *molecular contact* and circuit *across an air film*, but it is evident no *arc* can accompany this transmission.

Prof. Blyth has however proved that an arc may be formed in the film of air and will act as a transmitter, but he used an E F M altogether out of practical range. It is also known that a variable arc lamp will give rise to sounds in a telephone.

1136. *Equal variations of pressure do not produce equal changes of resistance.*—Mr. Shelford Bidwell has published a very full series of experiments which show that the greatest variation occurs while the pressure is small, and that a limit is soon reached at which little effect is produced: it would appear as though the early action is to thin and squeeze out the air film, then to press more surfaces together until the limit of elasticity is reached.

1137. He also found that the *resistance varies with different currents*: therefore there is something besides resistance to be considered. The resistance *varies most* with small currents, pressure being constant, but is lowered by the increase of current, pointing to an action of the heat developed at the contact, which is not readily conducted away, because carbon is a bad conductor of heat.

1138. PRINCIPLES OF CONSTRUCTION.—The adjustment and the resistance must be suited to the required purposes: for very slight sounds or motions the moving parts must be very light and the capacity of motion very delicate: but if such an apparatus were used to transmit speech, little more than a continuous roar would be heard. For this purpose heavier masses, greater pressure, and, as Prof. Hughes indicated from the first, several separate junctions are required, as now used in the Gower transmitter. This consists of a sound-board, to the middle of which a round block of carbon is attached, having six conical holes around it; six corresponding blocks are arranged in a circle around the sound-board, and pointed carbon rods connect them: three of the blocks on each side are connected together, and to one terminal, so that the system acts as three pairs of contacts in multiple arc, and two in series.

1139. The principles for a speaking microphone may be conveniently stated nearly in Mr. Bidwell's conclusions from his experiments: (1) The constituents (moving carbons) should be numerous. (2) They should all be in multiple arc. (3) They should be heavy, to give inertia. (4) The pressure should be light, by adjustment. (5) The resistance should be small, and adjusted to that of the whole circuit. (6) The current should be large in the whole, but small at each contact.

1140. DISTANCE OF TRANSMISSION.—There appears no reason why *mere distance* should be of any moment, nor the mere resistance of the circuit. Prof. Bell, at an early period, spoke through 250 miles and through 60,000 ohms. Statements have been made lately as to working through 1000 miles and even 1500, but this latter was in Australia, *with no surrounding actions.* Sermons are said to have been heard 100 miles away, but that indicates a special quiet time. It appears unlikely that practical work will be done over any serious distance, because *distance involves induction*, § 1129. Though two wires may protect against *external* induction, and wholly remedy that evil for short distances, they will create it for long ones in the form of "retardation." It is shown, § 106, that current is propagated step by step, and in § 95 that this and "charge" are simultaneous and inter-dependent; therefore with two wires + and − at one end, the circuit must charge and discharge the dielectric which separates the wires at every change of current, before it can transmit a working current to the distant end. The rapid changes of telephony must therefore soon overlap and confuse each other. For long distance a circuit of very small inductive capacity is necessary, and this would require the two wires to be at some distance apart and free from separate external induction.

1141. TELEPHONE SYSTEMS.—Space will not permit the description of the arrangements of the regular telephone "exchanges," nor is it necessary, as those concerned in them must abide by the arrangements in each case. But it may be useful to show such a system as any person can employ for personal requirements. The actual apparatus to be employed will be readily selected and made by those who comprehend the general descriptions already given, and who are capable of such work, while there are plenty of manufacturers ready to supply suitable apparatus to those who require their aid.

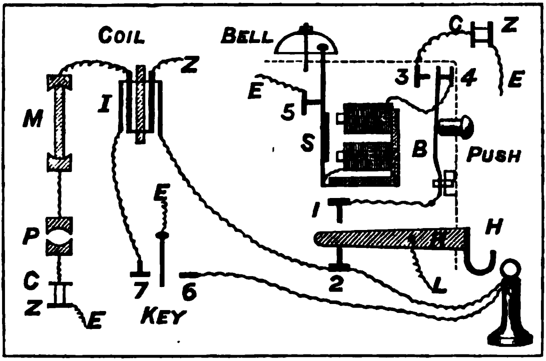
The line wires should have as low resistance as possible, and double wire of 18 gauge ozokerit insulated is made up for the purpose. Earth circuit may be used where not subject to induction.

A *call* is a first essential, and many attempts have been made to make the telephone itself serve, but the ordinary bell is generally used, now that battery currents are again employed. A rough call may be made with a tambourine having a piece of iron on its middle, acted on by an electro-magnet.

The call may be actuated direct, or a relay can be used to set a local battery in action; with a polarized armature this will also enable the speaker to select which of two instruments he may desire to address, according as he sends positive or negative currents to the line by means of a reversing commutator.

1142. Fig. 123 is a diagrammatic explanation of the principles of a complete circuit, the actual arrangement of which may be greatly varied. L is the line wire connected to the movable lever or spring H, upon which the telephone is hung when out of use, so that its weight shall place H in contact with the point 1 and the call system: this circuit then passes by the spring B to point 4 connected to the electro-magnet, and thence through the vibrating spring S to E. E represents the earth-plate or return wire, to which various connections have to be made.

Fig. 123



If the other instrument is to be called, the push puts B in contact with point 3, by which the positive pole of the battery C is put to line; Z, the negative, being permanently to earth; this sends out a current which acts as just described in the other instrument.

Unhooking the telephone puts the speaking system in circuit, as shown, by means of a double contact key or switch, put on point 6 to receive, and on point 7 to send a message, its moving arm putting either the telephone or transmitter to earth as required.

The transmitter, of whatever form, shown as a simple microphone M, is connected to the battery through a switch or plug P, to cut it off when not in use, the current passing through the primary of the induction coil I, and to the zinc of the battery. The secondary wire completes its circuit through point 7, and the switch to its own earth, and through point 2 and H to the line and the distant instrument earth.

If a simple telephone is used to speak through, its second wire is put to earth instead of to point 6, and the one telephone employed for both speaking and hearing, or two connected in arc or series, may be employed.

1143. RADIOPHONY.—One of the most interesting of recent discoveries, on scientific grounds, is the extreme sensitiveness of matter to the smallest variation in the streams of radiant energy. To the ordinary perception it appears that changes of temperature require considerable time to produce any effect upon matter, but we now have learnt that they are attended with great molecular changes, modifications of structure and properties, which occur with a rapidity comparable only to the speed of light, and which show, as stated § 847, that each molecule of matter is the centre of action of many forces, and swayed instantly by any change of relation among those forces.

1144. *Sound*, as explained §§ 983 and 1094, is simply a *vibration* which is perceived and measured by a special organ, the ear, but which may also be seen and felt. Like light, it involves a *source, a mode of propagation, and a receiver*, and like light it may be propagated in circular waves around its source, or concentrated in a "beam." Its vibrations may also be taken up by a resonant surface, such as a sound-board, which then becomes a new source.

1145. *Wheatstone's lyre* illustrates the principles to be borne in mind. If a musical box be set playing, its sound will not be heard in a room several stories above, even if a small opening be made through the several floors; but if through these openings there passes a light rod of pine-wood, resting on the box, or a resonant table on which the box stands, and terminating above in a sound-board, then the music will be heard in the upper room. The reason is, that air is actually one of the worst transmitters of sound, though the usual means of transmission: pine-wood transmits sound much more freely, and with about sixteen times the velocity. It is on this principle that the "stethoscope" is based, and enables us to hear sounds in the interior of the body, which cannot be perceived by the ear alone.

1146. A beam of radiant energy may be compared to the rod of Wheatstone's lyre, or to the cord of the string telephone, which both transmit a stream of energy, and the essential point of radiophony is that, if the stream of energy is made intermittent, the intermissions correspond to the successive impulses in the rod or cord, and that such impulses, falling upon a surface, may excite such momentary expansions and contractions as will generate sound-waves, just as though the resulting molecular undulations were caused by an actual vibration. This effect is in fact identical with that considered as occurring in the telephone, § 1112.

1147. The *simplest interrupter* is a metal disc mounted on an axis, and with a number of equidistant holes formed near its edge, the beam of light being condensed upon the point cut by the holes when the disc is rotated. Now this is one form of "siren;" for properly fitted, with a stream of air directed on the holes, we produce a musical note, varying with rate of rotation. In like manner, if we make the disc of iron, and place an electro-magnet with a telephone in its circuit on one side, and a magnet pole on the other, we have the *magnetophone*, which produces the same notes. We thus trace the connection from the rough mechanical action through the hidden actions of light and magnetism, just as in §§ 982–6 we trace the analogies of wave motion from the surface of a pool to the glories of the spectrum.

1148. *The radiometer*, when first invented by Mr. Crookes, was supposed to move by the impact of streams of radiant energy, as light; but it is now well understood that the motion is due to a more material impact, to the succession of blows given by molecules of the residuary air in contact either with the walls of the globe, or condensed upon the moving vanes and acting by "recoil," these molecules absorbing the energy of the radiant force. This same action is that which is operative in radiophony proper. The vanes rotate on their axis because their two sides have different absorptive powers, and therefore there is always a tendency in the most active side to retreat from the line of light, just as a horizontal windmill rotates in a stream of air because the vanes on one side present a flat surface to the wind, while those on the other side lie edgewise to it.

1149. One of the most remarkable experiments of Mr. Crookes is that of a radiometer with vanes coated on one side with selenium, and on the other with chromic acid. He found that light from a sperm candle, giving white light, repels the selenium, while that of a wax candle, with yellower light, repelled the chrome, indicating the relative absorptive powers of the different substances for rays of different refrangibility, resulting in mechanical motion, just as the same selective capacity operates in photography as chemical action.

1150. If a radiometer disc were mounted on an elastic support, and placed at right angles to an intermittent beam, it would doubtlessly vibrate to and fro in unison with a stretched cord giving a note corresponding to the intermissions: it would not produce *sound*, because sound cannot traverse a vacuum, unless the varying tensions on the glass might result in sound, but a beam of reflected light would show the motion. Something analogous to this occurs in direct radiophony, § 1160, but both for order of discovery and for convenience of explanation it is better first to examine the indirect action through the aid of electricity by means of selenium.

1151. SELENIUM.—This substance, which is chemically of close kindred to sulphur, manifests in a most striking degree the instant variation of the properties of matter under changes of external forces. Like sulphur, it passes into several different states, according to the conditions of fusion: it may be amorphous or vitreous, when it is non-conducting, and insoluble in bisulphide of carbon, or when very slowly cooled after fusion, it becomes crystalline and conductive, and also soluble; changes resembling those of phosphorus.

Willoughby Smith, while endeavouring to use the material for large resistance measures in 1873, discovered that this resistance was in some cases very variable, and traced the variation to the action of light; he used a bar of selenium with platinum wires melted into its ends, and found the resistance of 1400 megohms when the room was dark, reduced to 1000 when the gas was lighted.

1152. It has now been ascertained that the rate of variation of resistance under light is as the square root of the intensity of the light, so that it was proposed to use selenium in photometry: but unfortunately the property is not constant, but varies spontaneously as does the actual resistance. Prof. W. G. Adams has found a variation from 1,525,000 to 3950 in 12 months, and in another piece from 7,600,000 to 745, without any use having been made of them in the interval.

1153. There have been debates as to whether the action is due to light or to heat, really a discussion without meaning; but it would appear that the power is exerted by particular rays of the spectrum, as indeed is almost universally the case with radiant energy. The most active rays are those found on the green side of the yellow rays; but some experimenters have also found an active region in the ultra red or dark rays, and when a ray of sunlight is intercepted by a sheet of ebonite, an invisible beam passes which may be condensed upon the selenium cell; if a perforated wheel now renders the beam intermittent, the apparatus gives out the musical note in the telephone.

But *temperature*, as distinct from radiant energy, acts differently and apparently not alike in all samples. Some find resistance increase with heat and some find it decrease, and there is reason to believe that each sample has a "critical point" at which a reversal occurs, just as in thermo-electric actions.

1154. There appear to be several distinct actions: (1) light produces a gradual reduction of resistance, which gradually falls on withdrawal of light; (2) there is an instant decrease and as instant a recovery, these being the actions utilized.

There are different opinions as to the cause of these changes.

(1) Dr. Moser claims that there is not a true union between the metal and selenium or selenide, but only a microphonic contact modified by expansion and contraction.

(2) Siemens considers that besides the two allotropic forms, § 1151, amorphous and crystalline, that there is a third, *metallic*. He found that at 80° C. one change occurs accompanied with a loss of latent heat or energy, and another at 200° C. attended with a further loss, but that only a small part of the mass can undergo this change, which is also very unstable. He attributes the action to this last change occurring among the superficial molecules under the action of light.

(3) Prof. Adams and others find that there is an internal E M F set up in the selenium, acting with the current, and that the change of resistance is only an apparent result of this; see end of § 454.

1155. *Selenium cells*, as the receiving apparatus are called, are made in different forms, the object being to obtain as low a resistance as possible, with a small surface to receive the light. Various metals may be used as electrodes, but silver will not suit, because it is strongly acted on by selenium, nor will aluminium, because the two will not unite at all; platinum is unsatisfactory for the same reason in a lower degree, and either copper or brass is most suitable.

(1) Mercadier's cell is the simplest; it consists of two strips of thin metal, such as tinsel foil, fitted with conducting wires, separated by somewhat narrower strips of dry paper, tightly wound up as a spiral to the desired size; the face is then filed flat, taking care no circuit is formed, and placed upon a metal plate heated by a gas flame just enough to melt the end of a selenium stick and run it into the spiral groove: it should cool slowly and show a granular surface of a slate colour.

For spectrum experiments the foils must be wound into a narrow flat band.

(2) Prof. Bell used alternate discs of brass and mica treated in a similar manner, so as to form a cylindrical cell which would be acted upon all round when placed lengthwise in the focus of a parabolic reflector.

(3) *Annealing.*—This was at first effected by prolonged heating at 214° C., or the point at which the particular sample has the most conductivity (the fuzing point is 217° C.), and then allowing to cool very gradually for many hours, some passing current all the time; careful warming is now found to be

sufficient, taking care to avoid excessive heat, and watching the changes which occur till the appearance described (1) is presented.

1156. PHOTOPHONY.—Willoughby Smith, besides discovering the action of light on selenium, was the first to "hear a ray of sunlight fall upon a bar included in the circuit of a telephone." Others also had conceived the same idea, and were working at it, but Prof. Bell in conjunction with Mr. Tainter was the first to perfect an apparatus to transmit speech by a ray of light, and to realize what he called "the extraordinary sensation of hearing a beam of sunlight laugh, cough, and sing, and talk with articulate words."

This is effected by producing undulations in the light intensity, corresponding to the air waves of sound, and by the use of selenium receivers of low resistance, such as 300 ohms when dark, reduced to 150 in the light.

1157. There are various modes possible for producing a ray of varying intensity, and as a matter of curious scientific interest, we may note the suggestion of passing the light first through a Nicol's prism, and then sending one of the polarized rays through a glass tube containing bisulphide of carbon or other rotatory liquid. The wire from a telephone being wound in a helix round the tube, the varying current caused by speech in the telephone would vary the rotation of the liquid, and therefore also the quantity of light passing. In this way a solution of sugar might be made to report upon its own saccharine value by the strength of a note passed into the sonometer.

1158. The *simplest transmitter* consists of a plane mirror of flexible material, microscope glass answering perfectly: this forms the front of a chamber fitted with a speaking tube, in fact resembling a telephone disc with its lower face made into a reflector, which would send a reflected beam of light through the space of the magnet. A strong beam of light is concentrated upon the middle of the mirror, and after reflection is received upon a condenser and rendered parallel, so as to be transmitted to a distant parabolic reflector which concentrates the rays upon the face of the selenium receiver. The whole ray passes thus when the mirror is quiescent, but the impact upon it of sound-waves distorts the mirror surface, and rendering it more or less convex, proportionally scatters the reflected rays beyond the edge of the condensing lens, and therefore varies the strength of the luminous beam transmitted to the receiver.

1159. *Musical sounds* can be more perfectly transmitted than speech, and any desired note can be produced by the perforated disc, § 1147. Such notes can also be converted into signals on the principle of the Morse alphabet, by means of a key, which interposes an opaque screen in front of the opening in the disc so as to produce periods of sound and silence to represent the dot and dash signals. Where, as in war, a beam of light might be a source of danger, a dark ray may be serviceable, § 1163.

1160. DIRECT PHOTOPHONES.—Prof. Bell observed in his experiments, that the intermittent beam gave out sounds when simply falling upon a disc of resonant material, without the aid of the telephone. Further experiment in conjunction with Prof. Tyndall showed that nearly every substance tried in a thin diaphragm gave out sounds; attributing this to sudden expansions and contractions due to the absorption of heat, they tried vapours contained in a test tube fitted with a hearing tube: it was found that the vapour of sulphuric ether, which is powerfully absorbent, gave out notes, while bisulphide of carbon, which is diathermanous, was silent. We have here in fact sound produced by molecular vibrations, just as in the case of the telephone, § 1112.

1161. But it is very doubtful whether the sounds, or the molecular expansions resulting in sound, are due to the *surfaces* on which the radiant energy is received. It is found that a tube containing loosely packed spongy materials, which have no resonant properties, gives out the best sound, and also that a surface which when quite clean has little power, becomes sonorous when smoked, i. e. coated with lampblack, which is a well-known powerful absorbent of radiant energy. It appears therefore that the true cause of the sound is similar to that of the motion of the radiometer; that it is the energy taken up by molecules of air in contact with the receiving surfaces. As in § 1013, the energy traverses air itself without heating it, but the absorbent surfaces at once transfer the heat to the air in contact with them, and this air instantly has an impulse to motion which generates a sound wave.

1162. Mr. W. H. Preece suggested this explanation, and demonstrated it by using a case or tube containing a spiral of fine wire through which an intermittent current was passed: this, generating heat impulses, gave out a sound from the tube similar to those produced by the external ray. Perhaps even a more striking evidence is given by the action of a flask which filled with dry air gives no sound as a receiver, but does if filled with ammonia vapour, which absorbs energy: a difference which applies to the whole range of gases and vapours, which Tyndall, in his 'Heat as a Mode of Motion,' has shown to be divisible into absorbers and transmitters of energy according to the complexity of their molecular constitution, the more complex being "reduced" to simpler forms by the act of receiving energy, the fundamental law of chemical actions, and of the functions of vegetable life.

1163. The different capacity of different substances for absorbing radiant energy as light and heat is mentioned § 1008, and the fact that the same substance has very different relations to rays of different refrangibility, §§ 984 and 997. This is strikingly illustrated by glass, which freely transmits light rays, yet intercepts the long-wave heat rays.

Ebonite has just reverse properties: it is quite opaque to light, but in thin sheets a strong light may be seen through it, as a dull red colour; that is, it transmits the lowest of the red rays, and permits the ultra red rays to pass freely. If a sheet of ebonite be held in the path of the rays acting on a selenium receiver it prevents the production of sound, because the chief action on selenium is due to the yellow rays which ebonite refuses to transmit: but if the receiver is an ebonite disc or any material acting by heat, § 1160, the interposed ebonite produces little diminution in the sound. The effect is that an invisible beam of radiant energy falls upon the receiver, which may then be called a *thermo-phone.*

1164. THE INDUCTO-PHONE.—When two spirals of wire are placed parallel to each other, but unconnected, any current in one induces a current in the other, this being the basis of induction coil action. The quantitative effects vary as the square of the distance of two parallel coils, and the action is greatly influenced by those conditions which cause "retardation" and the number of breaks of circuit per second. Willoughby Smith has applied this action, and examined its details in a paper read to the Society of Telegraph Engineers, 8th Nov. 1883, in which is traced out the influence of diaphragms of materials interposed between the two spirals. The effect of such screens is clearly due to energy absorbed and given out at each change of condition, and therefore varies with the *capacity* of the substance, and with the rate of the changes. The disc of a telephone acts as such a screen and actuates the telephone, and even gives out sounds by itself when placed in the lines of force. A small spiral traversing the face of a large one measures the lines of force proceeding from the different parts. Mr. Smith suggests that communications might be made in this way between signalmen and a moving engine by means of spirals on the line, into which intermittent current could be sent, which would act on a spiral fixed on the engine. No doubt also some of the various systems which have been described will yet enable communications to be made from the land to ships at sea.

1165. TELE-PHOTOGRAPHY.—This apparatus for producing pictures or writing at a distance is an application of the properties of selenium, in combination with the chemical telegraph. In this, as described § 1079, a coloured mark is made at a distance when current is transmitted, and a facsimile of the original may be produced in the form of a series of dots and lines. A continuous current of greatly varied intensity would result in similar variations in the intensity of the lines produced; and such a variable current is producible by changes in the resistance, which changes are producible by light acting on selenium.

Mr. Shelford Bidwell made an apparatus for this purpose. The transmitter is a dark box, containing at one end a selenium cell forming part of the line circuit, and facing a small hole at the other end; the box is mounted on an axis, so as to move up and down, each upward motion corresponding to one rotation of the receiving cylinder, and so to one line on the drawing produced. The box also moves sideways at each stroke, to correspond to the distance of the lines apart. The face of the box corresponds to the screen of a magic lantern, and the picture to be transmitted is thrown upon it continuously, so that the pin-hole is, so to speak, an eye by which the selenium cells looks the picture over, and receives the influence of each part successively, as it traverses over the space filled by the picture. When a dark line is thrown on the hole, the resistance increases, while a white portion reduces it.

The transmitter is really a differential instrument: it receives the line current at one terminal, and that of an opposed local battery at the other, the line being also connected to the other pole of the battery, and resistances so arranged that the local battery acts and makes a mark whenever a dark line is to be produced, and thus the traversing style produces either no action at all, or coloured lines varying in depth of tone in correspondence with the amount of light falling upon the selenium cell from the distant transmitting illuminated picture.

1166. HUGHES' INDUCTION BALANCE.—This instrument is based upon the principles involved in the experiment described, § 456.

(*a*) It consists of two straight-sided cups or cylinders of wood, or other non-metallic substance, mounted on a board at least 3 feet apart, and equally removed from any metallic masses. Each cylinder constitutes an induction coil, having two separate coils of wire (say, each 100 yards of No. 32) placed parallel to each other on the cylinder. Two corresponding coils, connected in series, constitute the "primary" or inducing system, in which is introduced a battery and any convenient automatic contact break, such as a clock, fitted for the purpose, the sound of which ought not to be heard, so that it is best in another room. The other coils are arranged with reverse action to neutralize each other, and a telephone is inserted in their circuit which will reproduce the tick of the break if there is the least inequality of induction in the two pairs of coils. A suitable galvanometer might be used to give visible instead of audible evidence, and would *measure* the action; but the telephone is the most sensitive.

(*b*) *Exact adjustment* is effected by making one of the coils movable, and fixing it at such a point as is found to give no sound in the normal condition, for which purpose the coils may be made on light reels, sliding on the cylinders, or the cylinders themselves may have a screw joint in their middles, by which adjustment can be effected.

(*c*) Now, if any substance whatever be inserted in one cylinder, if it has either inductive or magnetic capacity, it will disturb the equality, and sound will be heard in the telephone, varying in intensity with the capacity of the substance. If two masses of the same substance be placed in the two cups, any difference in weight or form will manifest itself.

(*d*) It is evident that if the principle of adjustment be carried further, a scale of induction could be prepared giving the quantitative relations.

(*e*) In the course of time important uses will be found for this instrument. Thus, it will at once test spurious coin, for if a good coin be placed in one cup and a suspected one in the other, the telephone will at once speak for its character. The chief difficulty is the great delicacy of the instrument, as a difference in weight will cause it to complain.

(*f*) It was employed to endeavour to discover the locality of the bullet in the case of President Garfield; but it was deceived by the presence of metallic springs in the bed. Undoubtedly such applications will yet be made. A splinter of metal in a finger has been discovered.

1167. HUGHES' SONOMETER.—This is a special form of the balance adapted for examining either the loudness of sounds or the capacity of any ear for distinguishing sounds. It consists of a graduated rod mounted on a frame. At one end of the rod is fixed a coil A, such as just described for the balance; at the other end, projecting beyond the support, is a smaller coil B, containing 1 yard of the wire. The two coils are connected in such a way as to have opposite, but of course unequal, effects upon a coil C, similar to A, and sliding upon the bar. Of course relative nearness will compensate for difference of power in the two coils, and the length of the bar (usually 200 millimetres) should be such that, when the moving coil C is placed close to the small coil B, the most sensitive ear shall discover no sound in a telephone included in the circuit of C, due to the breaks made in the circuit of the two fixed coils by a clock or other break, in the same way as described for the balance.

A scale of audition can thus be obtained, as an absolutely deaf person will hear nothing, even when C is fully influenced by A by being brought close to it, and others will begin to hear the ticking at different distances. The scale will also give a range of sensitiveness, as a certain distance will be found between the points at which a sound is lost, and that at which it is again perceived.

1168. EDISON'S MICROTASIMETER.—This measures the minutest changes of pressure, and therefore of heat, of moisture, and many other agencies. It is in fact the transmitter, § 1119, in which the vibrating disc is replaced by a rod of a substance to be examined. It consists of a solid iron bed with two brackets cast with, or fitted rigidly to it. To one is attached an ebonite disc with a central chamber; through the middle of this passes a flat-headed screw faced with a platinum disc which receives current from a binding screw on the bracket; on the disc lies the carbon button with another platinum electrode as in the transmitter, connected to the battery. On this lies a cup to receive the end of a rod of material to be tested, the other end being supported by a similar cup fitted on a slide in the other bracket, the position of which can be adjusted by a screw. Of course, the arrangement might be vertical instead of horizontal. A suitable galvanometer is in the circuit, and the initial pressure is so adjusted that only a small deflection is produced.

A strip of ebonite placed between the cups shows extreme sensitiveness to heat changes which are not manifested by the thermo-pile: a hand held some inches away will give a deflection. A strip of gelatine produces the same effect by absorbing moisture from damp paper 3 inches distant.

For extremely delicate observations the instrument is placed in one arm of a Wheatstone bridge and balanced by a resistance. It would appear that the differential principle would be most perfect; two tasimeters balancing each other so as to neutralize surrounding actions, while the influence to be tested was concentrated upon one. However, the great difficulty of the instrument is its extreme sensitiveness. It ought to be placed upon an absolutely rigid support, free from all vibration.

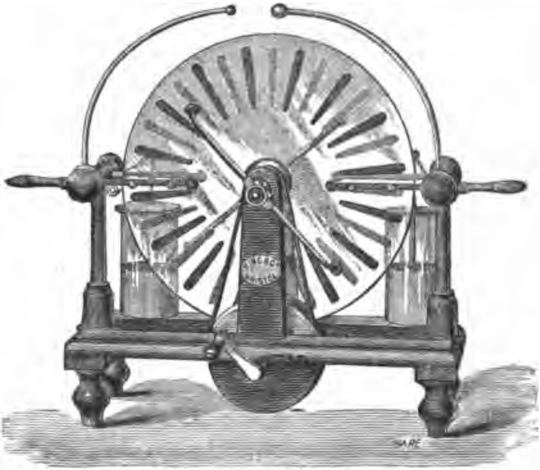
1169. A NEW SOURCE OF ELECTRICITY.—Mr. J. A. Kendall has observed that when hydrogen is passed into a tube of metal separated from another by vitreous substances heated nearly to the point of fusion, an E M F is generated, and if the tubes are connected together a current passes. It is known that platinum and other metals, when at a red heat, permit the passage of certain gases. The phenomena described in papers read to the Royal Society, September 30, and December 28, 1883, depend upon this property brought into action by the differential atmosphere on the exterior and upon the chemical union of the hydrogen in combustion. The gas would transfuse into any different atmosphere, but the electric action only occurs when this is an oxidizing one. The quantity of the electricity depends upon the area of the metal, as also upon its thickness, evident functions of resistance, but it is also related to the consumption of hydrogen, as in the battery it is to the consumption of zinc, which indicates a molecular action.

Becquerel and others made a "pyro-electric" battery of iron and copper in crucibles of melted glass, and in other ways worked closely on the lines of Mr. Kendall's discovery, but they did not recognize that the action had anything to do with the transfusion and combustion of gases, but attributed it purely to a chemical action on an oxidizable metal, as in other batteries.

Mr. Kendall has also found that while vitreous substances thus enclosed between two electrodes are incapable of conducting electricity under a low E M F (though glass conducts under high E M F when heated, § 97 (*c*), and its conductivity rises with temperature), yet they become conductors when hydrogen is present on one side, and an oxidizing atmosphere or a vacuum on the other. In this latter case the hydrogen passes through and a galvanometer in circuit shows the passage of current, not indicated at the same temperature when both sides are exposed to the same atmospheres.

1170. THE WIMSHURST MACHINE.—This is a modification of the Voss, § 52, which has been introduced since Chapter II. was printed, and is of so much interest as to require description. Fig. 124 will explain its construction with the latest additions, and also show its relation to the Voss machine and others. If only one plate rotated, the sectors would simply replace the discs of the Voss; the distinction lies in the opposite rotation of the two plates, which makes each act as inductor and induced surface, while both send electricity to the outer circuit, for which purpose the collecting combs surround both plates, as in the friction machine. This is the reason that the machine does not reverse itself as the Voss does, and is less affected by moisture, both important advantages. The plates are mounted upon wooden or ebonite bosses, as described p. 43, but the axis is a plain rod instead of conical, and passes from one standard to the other, projecting so as to carry the contact arms on each end, which are placed at right angles to each other.

Fig. 124.



The number of sectors varies with the size of the plate and the effect desired; with many narrow ones the machine charges with greater ease, but long sparks require a smaller number at greater distances, 12 to 16 being the most useful. They may be made of tin foil, but are better of thin soft brass with all corners rounded and the edges smooth, and with buttons soldered on to make contact with the brushes. They must be very exactly placed so as to make the proper circuits; the simplest plan is to draw the positions on a sheet of paper with mathematical exactness, then lay the glass on this and place the sectors by the marking, which is alike for both plates; they can be attached by coaguline, or better by shellac cement, both plate and metal being warmed to the proper point and coated. The best plan is to arrange a smooth plate of iron, or a sand bath, at such a distance over a gas flame or a stove as shall heat it to the proper degree, placing the glass on this so that it shall be equally warmed all over. When the sectors are fixed, the plate should be varnished with thin shellac varnish, which may cover the sectors, but not the contact buttons; when the sector side is dry, the warm plate can be lifted and at once varnished on the inner side. They should be fixed on their bosses with a cement, and adjusted as close together as possible, and it is well to hollow the ends of the bosses so as to allow the interposition of a washer or two to diminish friction.

1171. THERMO-ELECTRICITY.—The direct conversion of heat without the intermediary steam boiler, engine, and dynamo, is a tempting field for work, but so far, all known means are more expensive than the seemingly roundabout process, because the efficiency of conversion of energy is extremely low. Only about 2 per cent. of the heat is converted into electric energy. It would seem possible, however, to utilize much waste heat in this manner, by surrounding flues with thermo-electric elements; or the reverse process has been proposed, to make stoves the casing of which generates electricity, while radiators diffuse the unconverted heat for purposes of warmth.

1172. Heat is a vibratory molecular motion, diffusing energy in all directions in equally conductive matter; electricity is a rotatory molecular motion, transmitting energy in a linear path. Most substances have a similar conductive ratio for both, but for heat the conduction is slow, while for electricity it is instantaneous. The relation between the two appears to be, that electricity in its transmission always generates heat, and that heat in its transmission sets up an E M F wherever it crosses a junction of two dissimilar molecular conditions, the direction and the degree of this E M F depending on the specific properties and conditions of the substances. It seems probable that the real cause is a difference of atomic heat and conductivity; that the substance which has the higher capacity or conductivity for heat tends to convert energy into the electric form, as in § 537. Space will only allow a slight outline of the leading principles of this subject.

1173. The +, or *positive* metal or substance, is that whence a current passes across the heated junction within the system. This corresponds to the zinc in a battery. The E M F depends (1) on the specific substances, (2) on the difference of temperature at the two junctions, taking as a type the simple unit element of two wires, say iron and German silver soldered together at both ends, and the heat applied at one junction: intermediate junctions do not affect the result, because they neutralize each other. Thus, either the iron or the German silver wire may be cut and joined to a copper wire forming a galvanometer circuit, without affecting the E M F.

1174. The *absolute mean temperature* of the two junctions varies the E M F for a given difference of temperature, and even its direction; thus, near 300° C. copper and iron are neutral, but below that copper is + to iron, and above it iron is + to copper. This change appears to occur at a "critical point," at which softening or some molecular rearrangement occurs.

1175. Any *molecular change* will set up the action. Thus, it will occur in a single wire, if a portion is filed away so as to make a great difference in the heat capacity of the metal in the two directions; a stress upon a part in excess of the elastic limit, or hardening in the case of steel, makes the two parts act like different metals. Or if a hot wire be put in contact with a cold one of the same metal, it is found to be positive, because the heat suddenly passes over to the cold wire.

1176. The following figures show the E M F of various metals with lead near the ordinary temperatures, calculated by Jenkin from Matthiessen's experiments. The value is micro-volts per degree Cent.:—

Bismuth pressed wire	+97·	Silver	−3·
„ crystal axial	65·	Zinc pressed wire	3·
„ „ equatorial	45·	Antimony, pressed	6·
German silver	11·75	Iron, piano wire	17·5
Lead	0·	Antimony axial	22·6
Copper, commercial	−1·	„ equatorial	26·4
Platinum	·9	Selenium	807·

Under like circumstances Clark obtained from:

Copper and iron.	Volts	·006	Antimony and bismuth	·0051
Platinum „	„	·0011	Clamond's alloy and iron	·0102
German silver and iron	„	·0020		

Some alloys are found most powerful, especially after frequent meltings. Marcus uses a German silver as + metal composed of 10 copper, 6 zinc, and 6 nickel, and for − metal an alloy of 12 antimony, 5 zinc, and 5 bismuth, and other alloys are mentioned later.

Galena, sulphide of lead, and *pyrites*, sulphide of copper, have been used as materials for piles, as also other non-metallic conductors.

1177. *Thomson effect.*—If a wire is heated at one spot, the heat will extend to equal distances on each side: if current is passed this equality will be disturbed, and the heat will extend further on one side. In copper the current, as it were, drives the heat before it, in iron it draws the heat towards it. Some speak of this as the "specific heat of electricity," which they say is + in copper and − in iron; but this is a phrase without meaning. The action itself serves to measure the thermo-electric capacity of a substance, and because it is *nil* in lead, that metal serves as the datum of comparison.

Peltier effect.—See Dictionary of Terms.

1178. THERMO-ELECTRIC PILES.—For scientific purposes these are usually made of bismuth and antimony, because these give the highest E M F; the metals are cast as small square rods, with lugs on the ends for connecting together.

Dr. Gore has described a pile made of German silver wire ·7 mm. and iron wire ·55 mm. mounted on a frame so that the ends dip on one side into melted paraffine, and on the other into non-volatile petroleum or thin machinery-oil contained in troughs. He finds with 295 pairs and a difference of 130° C. an E M F of 1·005 Volt or ·000062 per pair per degree C.; he finds this very suitable for measuring E M F.

In all cases the edges should be carefully united with solder suited to the temperature to be used. For large piles, especially when high temperatures are to be used, a plate of metal should be interposed to act as collector of the heat on one end, and as radiator on the other; copper is best, as a good conductor, where the heat is not too great; on the cooling end it should be painted with lampblack and size.

1179. *Clamond's pile* excited great expectations some years ago. He used iron for + element in the form of sheet tin bent into a cup with an inward projection or dovetail. The — element was a bar 2–3″ long, and $\frac{3}{8}$ by 1″ in width, of two parts antimony and one of zinc; these were cast in a mould containing a sheet iron cup at each end, with projections for uniting the pairs together. These were mounted in circles, and again ranged to suitable height, the whole being bound together and insulated with powdered asbestos and soluble glass. The heat was applied in the tube thus formed, with a protecting cylinder of fire clay, between which and the face of the elements the heated products were drawn downwards by a flue.

1180. *Noe's pile,* though less ambitious than Clamond's is much used in Germany for laboratory purposes, to replace batteries: it is made of German silver and zinc antimony. The end of the — bar is cast into a cup of brass or German silver, into which a German silver wire enters, as also a projecting copper rod: twenty such pairs are arranged in a horizontal circle with these rods pointing to the centre, so as to receive the heat of a Bunsen burner, which they carry to the end of the element. The outer end of the bar is soldered to a plate of copper terminating in a cylinder of the height of the instrument, up which a stream of air is drawn to cool the outer junction. The — bars are about 1 inch by $\frac{1}{4}$ in dimensions, about ·025 ohms resistance, and give about ·0666 Volt E M F.

1181. CONSERVATION OF ELECTRICITY.—This is an idea set forth about the same time by Prof. S. Thompson and M. Lippmann, but with some differences. M. Lippmann embodies well-known facts in a mathematical formula, and Prof. Thompson says the doctrine "teaches that we can neither create nor destroy electricity, though we may alter its distribution." The doctrine appears to have no real meaning at all, and is only intelligible if we consider electricity to be an actual entity or fluid; in that case it is of course indestructible, like matter and energy. All the facts connected to the doctrine are equally consistent with the conception of electricity as a molecular action of energy, because the molecular or equivalent constitution of matter is itself unchanged, and the "quantitative" molecular action which is known as "electric quantity" is also definite, and must therefore remain constant through all the changes of electric action.

COUPLING OF CELLS IN BATTERIES.

In *series*. For intensity. High resistance.	*Circuits.*	*Parallel* or *multiple arc*. For quantity. Low resistance.
$(\underset{1}{+}\overbrace{-)\,(\underset{2}{+}}\overbrace{-)\,(\underset{3}{+}}-)$	*Connections.*	$\left\{\begin{matrix}(+-)\\(+-)\\(+-)\end{matrix}\right\}^{A}$ or $\left\{\begin{matrix}(+-)\overbrace{(+-)}^{B}\\(+-)\underbrace{(+-)}_{1\quad 2}\end{matrix}\right\}$

ELECTROMOTIVE FORCES.

E.M.F. of 1 + 2 + 3	are as	That 1 cell in A. of 1 + 2 in B.

RESISTANCES.

Sum of those of the separate cells.	are as	The reciprocal of the sum of the reciprocals of those of the cells in arc.

Using different kinds of cells.

Various kinds may be used together, but all should have equal capacity for current.	Cells must be equal in E.M.F., but may be of different resistances or capacities. Each series must be of equal E.M.F.

Capacities of cells.

All should be so balanced that they will work together, and not allow *some to be exhausted* before the others.

The same principles apply to secondary batteries.

CHAPTER XV.

DICTIONARY OF TERMS.

THIS chapter is intended to supply concise definitions of terms for occasional reference or to recall their full explanation to the mind, but in some cases information is given on subjects not noticed in the other parts of the book.

Absolute, see Units.

ACCUMULATOR.—Another name for secondary batteries.

AGONIC LINES.—Lines running through those parts of the earth in which the terrestrial and magnetic meridians coincide: i. e. where there is no variation.

AMALGAMATION.—Zinc is protected from waste by having its surface coated with mercury. For the process with zinc, see p. 124; for other metals, p. 390.

AMPÈRE.—The B.A. unit of current (see p. 234).

AMPLITUDE.—The extent of swing, as in a pendulum, or the *height* of wave-motion; the strength of wave-action, as the loudness of sound, depends on this, while the character, as pitch of note, depends on wave-*length* or time.

ANION.—The electro-negative, acid or chlorous radical of the salt or acid decomposed. Oxygen, acid radicals, as chlorine are anions (see Ions).

ANODE.—The positive electrode or pole of a battery; the wire or plate connected to the copper or other negative element of the battery; the plate which leads the + current into a solution to be decomposed, and at which are set free the oxygen, acid radicals, and all − ions (anions). In electro-metallurgy it is usually formed of the metal to be deposited, in which case it is called the soluble anode or pole.

ARC.—The air space in which the electric light forms; it contains carbon vapour and gives off the violet rays which render the arc light so steely in character.

Arc, see Multiple.

ARMATURE.—The keeper of a magnet. *Armature of dynamo machine:* the part which, like the *keeper*, closes the magnetic lines of the field magnet; it is usually the moving part.

Astatic.—Without inherent directive power; usually applied to pairs of reversed needles, § 309.

Atom.—The supposed ultimate particle of the elements, p. 2. There is still much confusion as to the terms atom and equivalent, which were formerly used for the same purpose, but modern chemistry attaches a distinct idea to the atom, which correlates it, not only to chemical affinity, but to heat and other forces.

Atomic Weight.—The relative weights of the atoms as compared with that of hydrogen taken as 1. At p. 319 is a table of the atomic weights and other particulars of the elements most important in electricity.

Balance.—See Bridge. *Hughes' Induction*, see § 1166.

Ballistic Galvanometer.—This measures a momentary current such as a discharge of a condenser, just as a ballistic target measures the impact of a shot. It requires a heavy needle, presenting little surface to the air. The quantity of electricity is proportional to the *sine of half the angle of the first swing.*

Base.—See Radical.

Battery.—A combination of voltaic cells. The word is commonly—but erroneously—used for a single cell (e.g. Smee's battery), but it strictly means two or more cells coupled together in series. The term is also applied to similar combinations of Leyden jars.

Break.—See Commutator.

Bridge.—Wheatstone's. An apparatus for measuring resistances by balancing the unknown R against one known and capable of regulation, p. 243.

B.A.—British Association. See Units.

Brushes of *dynamo machines*; the collectors of the current.

Calorimeter.—Instruments for measuring heat produced; for electrical uses, they are, in fact, thermometers; but for measuring the heat produced in chemical actions, &c., very elaborate instruments are made, as described in treatises on Heat.

Candle, *Electric.* An arc light generated at the end of two carbon rods arranged side by side, and burning away equally. First made by Jablochkoff.

Candle-power of light.—The legal standard for measurement of gas is a spermaceti candle of six to the pound burning at the rate of 2 grains per minute.

Capacity.—The power of a surface or dielectric arranged as a condenser to hold electricity as "static charge." Its unit is the farad.

Cascade, *charging in*, is the old term for Leyden jars arranged in *series*, like voltaic batteries.

Cathode.—The negative pole of a battery; the wire or plate connected to the zinc; the plate at which, in any decomposition cell, the cations or + ions are set free. In electro-metallurgy, the object upon which the deposit is to be formed is the cathode.

Cation.—Electro-positive elements and radicals, which are set free in electrolysis at the cathode. Hydrogen and metals in the order of the electric series are cations. See Ions.

Cell.—Each separate vessel in which a chemical action occurs, forming part of the electric circuit. Thus there are the active or generating cells—i.e. those which form the battery, and the decomposition cells, and these last may be of two classes: (1) Passive or mere resistances, such are those employed in electro-metallurgy where the metal is dissolved from the anode, and simply transferred to the cathode; (2) where chemical force is exerted and absorbed in effecting true decomposition, as in the gas voltameter.

C.G.S.—Centimetre Gramme Second. See Units.

Charge.—The measured quantity of static electricity accumulated on a conductor or a condenser.

Chemic.—See Current, Units of.

Chlorous.—Pole, a term sometimes used for the negative pole, or cathode. A chlorous radical is that radical of a salt or acid which answers to chlorine in HCl—that is, it is the acid radical or electro-negative element or anion.

Circuit.—The path along which the current travels, or in which electric tension is set up.

Conductive circuits are those through which current passes, and are composed wholly of conducting materials.

Inductive circuits apply to static electricity, and are partly composed of insulating materials, as air or condensers.

We may conceive a conductive circuit as represented by an endless chain driven by a drum to which force is applied (this representing the generator); such a chain will drive any machinery to which it is connected, as the current does work. The inductive circuit resembles more a single chain acting on a spring, like a bell-wire, so that only single impulses can be given, and on release the spring restores the energy.

Derived circuits are a division of the path in two or more parallel branches.

Commutator.—Break, contact-breaker, and circuit-changer. They are of many forms according to the purpose required; a simple spring pressing on a point serves for a mere break or interrupter of the current, but the arrangement is often complicated when it is necessary to provide several different circuits for the current.

CONDUCTIVITY.—The degree of power to permit current to pass; it is the opposite of "Resistance," which see.

CONDUCTORS.—Substances which permit electricity to pass. It used to be thought that substances were of two distinct classes, conductors and insulators; but it is now known that it is only a question of degree of resistance. Silver is the best conductor, then other pure metals, then alloys; solutions of electrolytes follow, but at a long interval. Current passes through conductors in the ratio of their sectional area, and the inverse ratio of their length.

CONNECTIONS.—Wires, &c., completing the circuit between different apparatus; they should be sufficiently large, and of copper so as to give little resistance. There is often much trouble caused by the stiffness of stout wires, it is therefore well to form a spiral upon each connection, so as to give a little elasticity. The best connections, however, are made of wire cord, such as is made for window sash-line, or by twisting up fine copper wire into a cord; lengths suited to various purposes should be cut, and to the ends should be soldered pieces of No. 12 copper wire, of a couple of inches long, for insertion in binding-screws. If these ends are well silvered or gilt, much trouble in cleaning will be saved. Annoyance from accidental contacts, &c., is also avoided by covering these conductors with narrow tape plaited on, and soaking with boiled oil.

For *uniting wires*, blocks of brass are very useful with two parallel holes drilled through and a screw to press in each. A very simple and convenient connection may be made with a piece of 18 copper wire 3 inches long, which is to be hammered flat for 2½ inches and filed smooth so as to give it spring: it may then be tinned with a soldering iron, or preferably nickelled or gilt, and then wound up in a helix upon a piece of iron wire larger than any wires it is to be used with: it can be then curved so as to grasp a wire end pushed into it. Two of these joined together or made on the ends of one piece make a perfect connection; they can be joined in any number; and at a time when the writer was unable to obtain binding-screws and consequently devised this plan, instruments were entirely fitted up with them, and have remained so fitted, and useful for 30 years.

Wood-screws make convenient connections if a piece of wire is soldered in the cut, to turn them with; a piece of sheet metal with a wire attached to it may be placed in the hole in which they work, and a metal washer under the head to grip a bent wire placed under it.

Consequent Poles.—Where, intentionally or accidentally, two N or two S poles are formed together S—N N—S, in which case we have, apparently, a magnet with two similar poles at its ends.

Constant.—A value which correlates individual cases to general laws. The constant of a galvanometer is the value in ampères corresponding to unit deflection; or it may be the resistance which, with a given battery, produces unit deflection.

Coulomb.—The B.A. unit of quantity, which passes in 1 second of an ampère current.

Current.—This word is used in many ways. The electric current means the supposed flow or passage of electricity or electrical force in the direction from + to – or positive to negative. It therefore originates at the zinc surface in contact with the solution, and passes from the zinc to the copper or other negative metal *in the liquid* of the battery, but *from* the negative metal to the zinc in the external circuit (see Positive and Negative). *Current* also means, scientifically, the measured work done chemically, or what was formerly called "Quantity" (which see, also Intensity of Current). For the laws governing this, see Ohm's Laws and Units. See Density.

Current, Units of.—The accepted B.A. unit is the *ampère*, which is the result of 1 volt of electromotive force acting in a circuit of 1 ohm resistance. Its chemical value is explained p. 270. It was formerly called a Veber.

The *Chemic* is used in these pages where it is desirable to keep in view the relation of electricity to atoms and molecules of matter, which it does more perfectly than the ampère, as explained p. 225. An ampère current is equal to one of 5·68 chemics, the chemic being 1 grain equivalent of action in 10 hours.

Declination.—The angular difference, at any part of the earth, between the nearest pole of the earth and the corresponding magnetic pole: it is the *variation of the compass.*

Density.—The "quantity" upon unit area of surface, which varies on the one surface according to form and nearness of surroundings.

Density of current, the same as with charge, in the case of electrolysis, which materially affects the action and the quality of deposit. Heat in wires is also proportionate to the ratio of current and section of the conductor.

Diaphragm.—A porous division between two liquids, through which electric current passes, and in which osmose occurs; and an E M F is produced as a result of capillary actions.

Dielectrics.—Non-conductors in which induction occurs, such as air and guttapercha.

Dynamometer.—This means "force-measure," and is the proper name for an apparatus which measures mechanical power, such as that exerted by a rotating shaft or a belt. It is often, but wrongly, applied to Weber's galvanometer, which consisted of coils in place of needles suspended within other circular coils.

Dyne.—The C.G.S. unit of *Force*, that which gives a velocity of 1 centimetre per second to 1 gramme weight, after acting for 1 second.

Earth.—Name derived from the old mistaken notion that electricity is pumped up from the earth as a great reservoir; *Putting to earth* and *earth connection* mean a general return circuit, which, for economy, is formed through the earth by means of "earth" plates, buried in moist strata at the various necessary points. But any conductor common to several circuits is technically called "earth."

Electrodes.—Faraday's term for the poles or plates leading the current into and out of a cell. See Poles, Anode, and Cathode.

Electrolysis.—The act of decomposition by an electric current.

Secondary electrolysis is a decomposition supposed to be effected by the chemical action of the substance really set free by the current (see Nascent). For explanation of this action, see § 605.

Electrolytes.—Bodies capable of being decomposed by an electric current. They must be composed of (or rather be capable of breaking up into) two radicals (see Ions); therefore, substances which contain three or more radicals are not electrolytes.

Electrometer.—Instrument for measuring electrostatic charge, or tension.

Electromotive Force.—The tendency to develop electric tension; in ordinary galvanic batteries the electromotive force is set up by the attraction of zinc for an acid radical; its degree depends upon the force and number of such chemical affinities in the circuit, and inasmuch as there are also opposing affinities tending to develop electromotive force in the opposite direction, the actual force depends upon the excess of the total affinities in the direction of the current, over those in the opposite direction.

Electromotive force may be either continuous or intermittent. Galvanic batteries and frictional machines set up a continuous E M F, which may be compared to gravity in its actions and laws.

Revolving magnets, charged condensers, the secondary wires of induction coils, set up a variable E M F, which may be compared to the energy of impulses and with the laws of projectiles. Such intermittent forces require a different mode of consideration and of measurement from those of a constant E M F, although the same fundamental principles apply to both.

The unit of E M F is the *volt*.

ELEMENTS.—The ultimate substances into which all the bodies we know can be resolved, and which, themselves, have not been resolved into any simpler bodies. There are 63 elements known, and several more suspected. They are assumed to exist in the form of *atoms*, and further information will be found under that head and under Equivalents.

ENDOSMOSE.—See Osmose.

EQUIVALENTS.—All chemical actions take place in a definite ratio, which is explained by the atomic theory as due to the combination of 1, 2, or more atoms of one substance or element, with 1, 2, or more atoms of others. Each element has its own equivalent weight, as compared with hydrogen as 1. There is much confusion of ideas, due to the change of modern chemistry from the old system of stating reactions in *equivalents* to the modern system of stating them in *atoms*. Table XIII. p. 319, gives a list of the equivalents. The relation of electricity to these equivalents is such, that in a chain or circuit composed of any variety of compounds of two of these bodies (which are, in fact, elements, radicals, and ions), the same current would release from combination the relative weight set against each substance. The weights themselves are relative or abstract, but in this work they are taken as "grains," for the purpose of getting a definite electric measure of current and work.

EQUIVOLT.—A unit devised by the author to connect together E M F and quantity. It is the energy engaged in effecting 1 equivalent of chemical action in a circuit of 1 ohm resistance, and under the volt electromotive force. It is described § 527. Its mechanical equivalent is 4673 foot-lbs. This unit, when thoroughly comprehended, will greatly aid in understanding electricity, and the doctrine of the correlation of forces.

ERG.—The C.G.S. unit of energy. The work of 1 dyne in 1 second.

Erg-ten, 10,000,000,000, ten thousand million ergs, written 1×10^{10} on the index notation explained p. 228.

Extra Current.—The induced current of higher E M F which appears in a wire, especially when wound in a helix, when the current is broken.

Farad.—The unit of *capacity:* 1 coulomb under 1 volt.

Field of Force.—The space between the poles of a magnet, or two electrically charged surfaces, and other active forces.

Galvanometer.—An instrument for measuring "current" by its magnetic effects in deflecting a magnetic needle. They are not comparable among themselves unless graduated for the purpose. The tangent and sine galvanometers are proportional, so that knowing the value of one deflection, all others may be calculated.

Horse-Power.—33,000 foot-lbs. per minute. The French "force-cheval" represents 32,560 foot-lbs.

Induction.—This is the name given to effects produced outside of the body exerting a force, or out of the circuit to which the force is directly applied. Thus a magnet induces magnetism in neighbouring magnetic substances, and then attracts them.

A static charged surface is said to induce an opposite electric charge upon surfaces presented to it; as to which see p. 34.

A current in a wire induces currents in other conductors parallel to it. See Secondary.

Inductorium.—A name for Induction Coils.

Inertia.—A word embodying the fact that matter will neither move or stop moving, except by an external action: the resistance to change of state of rest or motion.

Influence Machines.—Those on the principles of the Holz, Voss, and Wimshurst type.

Insulators.—Bodies possessing high resistance; all, however, allow some current to escape or rather "charge" to be lost as current. They are called "electrics," because friction develops electric excitement in them. Ebonite is the highest "non-conductor"; paraffin, sulphur, and glass follow. A full list is given p. 15. Telegraphic insulators are the porcelain cups, &c., to which the wires are secured, and which prevent electric communication being formed between the wires and the earth through the posts.

Intensity.—The old term for the properties now described as electromotive force and tension. Batteries were said to be arranged for *intensity* when the cells were coupled together in series. The term leads to such confusion that it is best abandoned altogether.

Intensity of Current.—A term adopted from the French *intensité de courant.* It means "quantity"; and the best writers now use the simple word "current," to avoid the confusion of these conflicting terms.

IONS.—Faraday's term for the two parts into which an electrolyte breaks up; they may be regarded as "radicals," and may be either single atoms of elements, doubled atoms which still act as one chemically, or they may be compound radicals, like cyanogen, ammonium, and the radicals of acids. They are of two classes, named from the electrode at which they appear; but it must be remembered that the same radical may be an anion at one time and a cation at another, according as it is united with a radical more or less high in the order of affinity. See Anions and Cations.

ISOCLINIC LINES.—Those drawn through places in which the dip is equal; in fact of magnetic latitude.

ISOGONIC LINES.—Those drawn through places of equal *declination*, or lines of magnetic longitude.

JOULAD.—The B.A. unit of energy, p. 236. It is sometimes called the *joule*, but that name has also been applied to the mechanical equivalent of heat, 772 foot-lbs.

KNOT.—The geographical and nautical mile, which some affect to write "naut," though the name is derived from the corresponding knots on the log-line used at sea: 2029 yards.

MEG-OHM.—The prefix *meg* signifies one million.

MICRO-FARAD.—The prefix *micro* signifies one millionth. The micro-farad is the practical unit of capacity.

MOLECULE.—The ultimate particles of free or complete substances. Modern chemistry draws a strong distinction between atoms, equivalents, and molecules, terms as to which there was formerly much confusion. The true meaning is fully explained pp. 5–8.

MULTIPLE ARC.—Cells connected parallel, or as derived circuits to each other so as to act as one large cell.

NASCENT.—It is found that substances have a much greater chemical force at the instant in which they are being set free from combination than when they are free bodies. They are then called "nascent." Most of the processes of electro-metallurgy are usually considered to be effected by secondary electrolysis, through this action of nascent hydrogen. This special energy is supposed to be owing to substances (or radicals) being then in the atomic instead of the molecular condition, and therefore having all their chemical energy or attractions engaged in seeking a combination. It is commonly the case, also, that a radical cannot be set free at all, unless in the presence of some other bodies with which it is capable of uniting.

NEGATIVE.—In the battery, the copper, carbon, or platinum plate.

Negative Pole.—Cathode, platinode.

Negative Ions.—Oxygen and acid or chlorous radicals.

NOTATION.—The mode of expressing chemical substances and reactions by their symbols. There are many modes of expressing the same things in different formulæ according to the special theory of constitution adopted, or the particular view of the matter intended to be described; and there are two distinct systems in use: the atomic or new notation, and the old equivalent notation.

There are also many ways of writing formulæ. That used in these pages is the simplest known, being based upon the binary theory of salts, and showing every atom in a reaction by its distinct symbol.

Some fanciful formulæ have been used lately, for the purpose of expressing particular theories on the constitution of substances. The most prominent is Frankland's, based on the hydroxyl theory. It is exceedingly puzzling, as it does not show real atoms, but the supposed compound radicals of the theory; and as Ho and Cuo mean something different from the usual HO and CuO, it is rarely written, and never printed correctly throughout.

OCCLUSION.—The absorption of gases by solids, with some change of property. The union of hydrogen with palladium is the most striking instance. The absorbing power of charcoal is sometimes called occlusion, but is probably of a different character.

OHM.—The B.A. unit of resistance. For its value see p. 232.

OHM'S LAWS.—These formulæ, devised by Ohm, enable us to calculate from certain data all the information we require. The symbols should represent fixed units (see Units) to obtain definite results. Otherwise they are merely comparative.

E stands for electromotive force, R for resistance, C for current. Any two of these being known we can calculate the third; thus knowing the force of the batteries to be used, and the resistance of a circuit, we can calculate the current generated, and therefore the amount of work to be effected under any given conditions.

E M F	Current.	Resistance.	Energy.
$E = C \times R$	$C = \frac{E}{R}$	$R = \frac{E}{C}$	$\left.\begin{matrix}W\\H\end{matrix}\right\} = C^2 \times R \times k$ $J = E \times C$

W means mechanical work, H is heat, k is a constant representing the suitable unit (pp. 236, 325), and J the joule or volt-ampère.

Osmose.—The process of diffusion of liquids through a porous division, which, like the diffusion of gases, shows that the molecules of matter in these states are in constant motion:

Endosmose and *exosmose* are names given to the two directions of the motion as related to any given vessel. Electric current and difference of potential give a stimulus to osmotic action, as explained p. 136.

Paraffin.—This valuable substance is obtained from cannel coal by distillation. Another form of the substance is called Ozokerit, or earth-wax. Its name (without affinity) describes its value, for it is scarcely acted on by any of the chemical agencies, acids, alkalies, &c.; it is also one of the best of insulating substances and resistants of moisture, and has many useful properties described p. 83.

Peltier Effect.—A current passing across a junction of two dissimilar metals absorbs heat (that is, cools the junctions) if it passes in direction of the current which heat would produce. If it passes in the opposite direction it produces heat, in excess of that due to the resistance.

Platinode.—Daniell's term for the cathode or that plate in any cell which does not dissolve.

Polarization.—The act of arranging the substances which form an electric circuit in a polar order or chain of + and − radicals, presented towards and reacting on each other. It resembles the arrangement which takes place in a number of magnetic needles which arrange themselves in an order of NS, NS.

Polarization of Plates.—This very confusing and absurd term is applied to an action which occurs whenever the current passes from liquid to solid conductors: there forms on the surface of the latter a film different from the liquid, by which there is not only a greater resistance introduced, but an electromotive force is generated, opposing that of the current, so that if suddenly connected to a galvanometer, and the main circuit broken, a reverse current will be maintained for some time. Secondary batteries are based on this action.

Poles.—The wires, plates, &c., leading from the battery: their name is the opposite of that of the plate they lead from; thus the zinc is the positive metal, plate, or element of the battery, but the wire leading from the zinc is the negative pole. This is fully explained pp. 118 and 175.

POSITIVE.—In the battery, the zinc plate; in a decomposition cell, the anode.

Positive Pole; +, the anode, the zincode, by which the current enters another cell.

Positive Ions; hydrogen, metals, and basic radicals.

POTENTIAL.—A mathematical term much misunderstood.

The *Potential* of a battery means its electromotive force.

Static potential is the corresponding stress exerted in the direction of the opposite electricities and is comparable to the pressure exerted by head of water.

Potential is studied as to its capacity to *generate current*, p. 265, and as representing stored work, p. 349.

Potential energy is stored work, capable of again doing work, as in a lifted weight, a strained spring, or chemical decomposition.

QUANTITY.—A term based on the idea that electricity is an actually existing element, having quantitative relations to chemical actions, similar to the atomic weights of the material elements. The definition applicable to existing ideas of the nature of electricity will be found under "Current." The *coulomb* is its B.A. unit.

RADICALS.—Either elementary atoms, or compound bodies which act like atoms, retaining their completeness and individuality through a series of chemical changes. It is considered that the acids are formed of such radicals whose attractions are satisfied by hydrogen, while salts are the same radicals satisfied by metals or compound basylous radicals. These radicals are the *ions* of the theory of electrolysis.

REDUCED LENGTH.—A term formerly used to express a resistance in the terms of its equivalent length of wire or resistance. It is now superseded by the definite expression in ohms.

RELAY.—A small instrument, such as an electro-magnet, which receives a feeble current from a distance and closes the circuit of a local battery so as to produce an effect of the required degree of strength.

RESINOUS electricity.—Negative, developed by rubbing ebonite, &c.

RESISTANCE.—The opposition presented by the circuit to the development of the current; it is an inherent property of every substance, varying in degree in each substance, from silver, the best conductor, up to guttapercha and the other so-called non-conductors. Whatever the special substance, however, its actual resistance may be expressed in any common unit; thus we may describe the resistance of a decomposition cell as equal to so many feet of a given wire. The unit of resistance now generally employed is the ohm.

Resistance is the reciprocal of the conducting capacity of a circuit: its relations to work, &c., are explained, p. 274.

Resistance requires to be considered in the various sections of the circuit as "internal," that of the battery itself; and "external," that of the work to be done, the conductors leading to it, and any measuring apparatus employed.

Resistance, when it is not work in some form, always converts the energy of the current into heat. See Ohm's Laws, and Units.

RETARDATION.—A term applied to the inductive action which reduces the rate of signalling in submarine cables. A signal to be transmitted requires a current at the receiving end adequate to the mechanical work to be performed in the instruments. The amount of that current is measured by the well-known Ohm's formula. But that current is not obtained in the receiving instrument at the instant of making contact at the transmitting end. A charge has to be given equivalent to the inductive capacity of the cable, and this charge acts as a resistance, great at first, but gradually diminishing to nothing. During this process the current at the receiving end increases as the momentary value of this inductive resistance diminishes, till it reaches the amount due to the ordinary wire resistance of the circuit.

RHEOMETER.—A galvanometer.

RHEOSTAT.—Resistance instrument. Wheatstone applied these names, and his early forms are described, p. 237.

RHEOTROPE.—A reversing commutator.

SECONDARY.—An action or a circuit depending on another.

SECONDARY ACTION.—See Electrolytes.

SECONDARY BATTERY.—See Polarization of Plates.

SECONDARY WIRE, in coils, is the long and fine outer wire in which the induced current is set up by the magnetic reaction of the core.

SHUNT.—A wire arranged to carry off a definite proportion of a current: a bye-pass to an instrument; another branch road as in railways, from which the term comes.

SOLENOIDS.—Helices of wire, which act as magnets.

SWITCH.—A commutator which will change the circuit to one of several circuits as required to be set in action.

TENSION.—The strain put upon the circuit by the electromotive force; it may be regarded as a single amount, or as + and − equal in opposite directions from the source. This term used to be employed in the sense now covered by potential, and much confusion still exists as to the meaning, as may be seen § 75.

THOMSON EFFECT.—An E M F exists between unequally heated parts of the same metal so that a current passing produces the Peltier effect, but different in different metals. In copper, current from hot to cold generates heat; in iron it absorbs heat or produces cold; and *vice versâ*.

UNITS.—The various bases of any system of measurement.

The Absolute are based upon the units of mass, length, and time, such as 1 gramme, 1 metre, and 1 second.

The C.G.S. system, in which the centimetre replaces the metre, is now generally adopted. Its unit of *force* is the *dyne*, and of *energy* the *erg*, and a complete system of electric values are related to these.

The B.A. system (the British Association), now universally adopted, is based upon the preceding, but consists of named units of convenient magnitude, as follows:—

Electromotive Force and Potential.—The *volt* = 10^8 C.G.S. units. The Daniell's cell, that is, the chemical affinity of zinc displacing copper from its union with sulphuric radical, is 1·079 volts; and therefore, for rough purposes, may be taken as a volt.

Resistance, the *ohm* = 10^9 C.G.S. units. Ohm measures made of German-silver wire can be obtained of scientific instrument-makers, and from them instruments for measuring resistances can be made as described, pp. 158 and 171.

Current.—The *ampère*, $\frac{10^8}{10^9} = 10^{-1}$, or ·1 C.G.S. unit per second.

1 ampère decomposes ·00142 grain of water. Formerly called veber.

Quantity.—The *coulomb*, the same value as the ampère.

Energy.—The *joulad*, the work done by one ampère in one ohm.

Power.—The *watt*, 1 ÷ 746 of a horse-power, expended in doing 1 joulad of work.

VEBER.—See Weber.

VITREOUS ELECTRICITY.—Positive, developed by rubbing glass.

VOLT.—The unit of electromotive force and potential. See Units.

VOLTAMETER.—An apparatus for measuring the current by its chemical action; the term is usually limited to a vessel provided with two platinum poles for the decomposition of dilute acid, and with tubes for collecting and measuring the gases given off.

VOLT-AMPÈRE.—Energy expended by current. See Joulad, which is the same.

Weber.—The old name for unit current, now the *ampère*. Some German writers use the name upon a system which gives it the value of 10 ampères.

Zincode.—Daniell's term for the anode, because, like the zinc of a battery, it dissolves.

To Guard Against Fire Risks in Electric Lighting.

1. See that *every part of the system* is insulated, and that *no part* has an "earth circuit."

2. If bare wires are employed, they should not lie upon a continuous support, as a line in a cornice, but be supported by insulators, which keep them away from surrounding surfaces.

3. Covered wires are most trustworthy; but they should be waterproof.

4. The two conductors should be as far apart as possible, and care should be taken that they do not approach metallic masses.

5. Risk of accidental short circuit must be guarded against, so that no piece of metal can fall cross the two wires, and no stratum of moisture be formed between them.

6. The size of conductors should be such that the proper current shall never raise it above 100° Fahr. and in each branch there should be a fusible conductor which will give way before an accidental current can raise the temperature of the conductor above 150°.

7. Arc lamps should be provided with a saucer to catch any falling fragments, a gauze above to prevent sparks from rising, and a wire netting around the globe.

8. The electro-motive force within a house should not exceed 200 volts with a continuous current, or 60 volts with an intermittent or alternating current.

9. High E M F is dangerous with the intermittent current, because of the violent "shocks" due to the "extra" current set up by discharge of the whole system at each intermission.

INDEX.

(*See also "Dictionary of Terms."*)

A.

Absolute (*see* Units), 226.
Acceleration in mechanics, 227, 260.
Accumulators, secondary, 172.
Accumulation, magnetic, 476.
Acid, battery solution, work of, 126.
——, strength and E M F, 328.
——, —— in secondary batteries, 182.
Acids, organic, in electro-metallurgy, 435.
Actinism, 552.
Adhesion, to prevent, 389, 393.
——, to secure, 388.
Affinity, chemical, cause of, 315.
——, —— (*see* Electromotive Force).
——, not suspended by electrolysis, 369.
Air as oxidant in cells, 165.
—— pumped into cells, 156.
—— film on surfaces, 388.
—— —— is a conductor, 604.
Alarms, electric, 590.
Alkaline nitrates, 150.
Allotropy, 5, 362, 611.
——, energy as cause of, 611.
Alloys in heat (*see* Resistance), 219.
——, nature of, 272.
——, depositing, 436.
Alum, chrome, formed in battery, 147.
Aluminium in batteries, 151.
——, depositing, 436.
Amalgam for machines, 39.
Amalgamation in plating, 390.
—— in secondary batteries, 180.
—— of zincs, 124.
Ammonia not a radical, 357.
Ammonium chloride, danger with, 372.
—— —— forms double salts with zinc, 161.
Ampère, the unit of current, 234.
——, chemical value of, 235, 270, 324.
Ampère-hour, the, 189, 235.
Ampère-turns, magnetic value, 511, 526.
Ampère's magnetic laws and theory, 96.
Amplitude, 624.
—— of sound waves, 598.
Angles, properties of, 197.
Anode, 356.
—— corresponds to zinc of cell, 358.
——, proper size of, 409.
Aqua regia in cells, 147.
Arc multiple, 280.
—— lamps, 566.
—— ——, differential, 567.
—— —— carbon arrangement, 565.
—— lighting, history, 558.
——, voltaic, 560.
——, ——, microphonic action of, 605.
——, ——, products of, 563.
——, ——, resistance of, 562.
——, ——, temperature of, 561.
Armature, magnetic principles of, 479.
—— drum, Siemens', 498.
—— ring, apparent, 480.
—— ——, true, 481.
—— ——, actions in, 495.
—— rotating over poles, actions in, 472.
Asbestite, 82.
Astatic needles, 194.
Atmospheric electricity, 445.
Atomic combinations, 3.
—— relations of energy, 120, 361, 571.
—— substitution, 6.
—— system, value of, 224.
—— weight and gas volume, 361.
—— ——, table of, &c., 319.
Atomicity (*see* Valency), 3.
Atoms, condensed, meaning of, 2.
——, imaginary dissociations of, 329.
Attraction and repulsion, 29, 54, 57.
—— distance, law of, 103.

Attraction, magnetic (*see* Magnetism), 103.
——, molecular, illustrated, 332.
Audiometer, Hughes', 616.
Aurora (artificially produced), 112.
Automatic transmitters, 584.

B.

B.A. system of units, &c., 225.
Balance (*see* Bridge, Induction).
Ballistic galvanometer, 624.
Batteries, galvanic (*see* Cells), 115.
——, arrangement of, 130, 166, 280, 623.
——, classification of, 117.
——, construction, 151.
——, cost of working, table, 171.
——, current from, 129.
——, enclosed cells for, 154.
——, electromotive force of, table, 336.
——, fundamental actions, diagram, 118.
——, secondary (*see* Secondary), 172.
Bells, electric, system, 587.
Berthelot's chemical law, 373.
Berzelius' chemical theory, 317, 362.
Bichromate of potash, 147.
Bjerknes' experiments, 102.
Blacklead for electrotype, 399.
Bound electricity, 71.
Brass, depositing, 437.
Break for coils, 535.
—— ——, mercury, 536.
——, double contact, 249.
Bridge, Wheatstone, principles, 243, 248.
——, ——, construction, 246.
——, —— and resistance, 250.
——, —— ——, decimal, 251.
——, ——, galvanometer for, 248.
Britannia metal, plating on, 391, 422.
Bronzing copper, 416.
Brown, J., on contact theory, 330.
Brush (*see* Discharge).
—— machine, 500.
Burgin machine, 480, 501.
Burnishing, 425.
Byrne's battery, 151.

C.

Calorimeters, 218.
Calory, two values of, 315.
Candle fired at board, 454.
—— standard of light, 555.
Capacity (*see* Dielectrics, Ener Magnetic).
—— and surface, 75.
—— of cylinders, plates, and spheres, 77.
—— of the earth, 235.
——, unit of, the Farad, 235.
——, spec. inductive, table of, 81.
——, —— —— and refractive index,
Carbon (*see* Cells).
—— absorbs light, 557.
—— anodes acted upon, 186.
——, artificial plates, 152.
——, connecting to, 153.
——, properties of, 152, 335, 337.
——, resistance of, 283.
——, —— and heat, 274.
Carbons for arc lamps, 569.
—— for incandescent lamps, 576.
Cascade, charging in, 626.
Cells (*see* Batteries, Decomposition).
——, circulation essential, 155.
——, ——, production of, in, 156.
——, each a section of circuit, 123.
——, electromotive force, table, 336.
——, enclosed, 154.
——, single liquid, defects of, 134, 136.
——, two liquid, principles, 135, 144.
——, size and forces of, 127.
——, two classes of, 357.
——, used as voltameter, 134, 139.
——, uses suited to, 171.
——, work capacity, 127; table, 168.
——, acids for (*see* Names of Acids).
——, alkalies in, 163.
——, alkaline nitrates in, 163.
——, aluminium as negative, 151.
——, aqua regia as oxidant, 147.
——, carbon in, 132.
——, ——, granulated, or rods, 154.
——, iron in, 132.
——, ——, peroxide and perchloride, 159.
——, platinum in, 151.
——, silver in, 132; platinized, 152.
——, saline solutions in, 146.
——, Bennett's, 164.
——, bichromate of potash, 156.
——, ——, Voisin's red salt, 150.
——, Byrnes', 151.
——, chromate of lime, 149.
——, Chutaux, 155.
——, Clark's standard, 162.
——, copper and zinc, 131.

Cell, Daniell, 136.
——, ——, E M F of, 140, 322.
——, ——, flat form of, 138.
——, ——, theory of, 140, 322.
——, ——, Callaud's gravity, 142, 143.
——, ——, Meidenger, Minotto, 143.
——, lead sulphate, 161.
——, Leclanché, manganese, 159.
——, mercury sulphate, 162.
——, nitric acid, Groves', 150.
——, silver chloride, 163.
——, Slater's iron, 158.
——, Smee's silver, 132.
——, —— odds-and-ends, 134.
Cement for glass, &c., 18.
—— for cells and wires, 138.
C.G.S. system, 227, 229.
Chains bad for conductors, 88.
Characteristic curve, 511.
—— —— of Burgin dynamo, 513.
Charge (*see* Induction), 53.
——, analogy to magnetism, 463.
——, distribution, 62.
——, division of, 30.
——, residual, 80.
——, supposed on the earth, 443.
——, theory of, fluid, 30.
——, ——, molecular, 31, 66.
——, to distinguish + and −, 19.
Chemic unit, explained, 123.
—— ——, why used, 225.
——, value of, 271, 324.
Chimneys and lightning, 455.
Chloride of ammonium, 161.
—— ——, dangerous to electrolyze, 372.
Chlorides, peculiarities of, 320.
Circuit, electric, 26, 28.
——, each cell a section of, 123.
——, formation of, 89.
——, inductive and conductive, 75, 76.
——, illustrations of, 331.
——, quantity equal at all parts of, 123.
Circulation in cells, 225, 408.
Clarke's typical dynamo machine, 474.
Cleaning for deposition, 389.
Clouds, state of, in thunderstorm, 451.
Coal, work value of, 519.
Coercive force, 111.
Coils, induction (*see* Spark), 530.
——, ——, coupling together, 540.
——, ——, dimensions for, 539.
——, ——, disc construction, 538.
——, ——, medical, 543.
——, ——, noted ones, 542.
Coils, induction, pocket size, 545.
——, ——, used with telephone, 600.
Colour, nature of, 550.
Coloured deposits, gold, 428.
—— ——, oxides, 583.
Colouring gold, 428.
Colours by arc light, 561.
Combination, chemical, energy of, 320.
Combustion, nature of, 316.
Commutator (*see* Connections), 167.
——, double contact, 249.
——, mercury cup, 209.
——, reversing, 541.
Condensation, 69.
Condenser, action of, in coils, 537.
——, effect of, on circuit, 80.
——, making, 52.
Conduction, nature of, 461.
—— in liquids, 297.
—— ——, without electrolysis, 378.
—— of heat, 301.
Conducting surface, to obtain, 398.
—— system for house, 587.
Conductivity and heat, 273.
—— and resistance, 272.
——, measuring, 291.
——, specific, 272.
Conductor (*see* Lightning), prime, 38.
——, dual development in, 90.
—— unit, defined, 354.
Conductors (*see* Wires), list of, 15.
——, law of cost of, 305.
——, ratio of size to current, 304.
Connections, various, 627.
——, brass blocks, 238.
——, care in arranging, 201.
—— in plating, 392, 412.
Conservation of electricity, 622.
Constancy, defined, 130.
—— of different cells, 168.
Contact and chemical theories, 327.
——, force disproved, 355.
——, Sir W. Thomson's experiments, 330.
——, theory explained, 328.
Contacts, microphonic, laws of, 603.
Convection of heat, 502.
—— of electricity, 378.
Copper, black coating on, 131.
——, depositing solutions, 414.
——, ——, rate of, 417.
——, effect on zinc, E M F, 141.
——, qualities of, 417.
—— wire, table of, 294, 295.
Core, coils, 530.

Core, iron helix, 465.
—— of electro-magnets, 525.
Cost of batteries, 142, 171.
——, energy, electrical, 521.
——, ——, mechanical, 520, 521.
——, light, electric, 581.
——, materials used, 170.
Cosmical electricity, 444.
Coulomb, unit of quantity, 235.
Coulomb-meters, 221.
Counter (*see* Electromotive force).
Crith, unit of volume, 224.
Critical points and allotropy, 611, 621.
Crompton-Burgin machine, 510.
Crystallization, water of, 297.
Current (*see* Density, Intensity), 18.
——, analogy, hydraulic, 268.
—— and energy, laws, 345, 353.
—— and resistance, reciprocal, 258.
—— as spiral rotation, 488.
——, definitions of, 256.
——, electric and hydraulic, difference, 257.
——, extra, 465.
—— equal throughout circuit, why, 357.
—— from Holz and Voss machines, 46.
——, heat of, 236.
——, in dielectrics, 79.
——, induced, theory of, 465.
——, ——, at make and break, why equal, 465.
——, laws of, 258, 267.
——, magnetic relation of, 190, 526.
——, square of, and work, 344.
——, tension of, 256.
——, units of (*see* Ampère, Chemic).
Currents, chemical values of, 384.
Cyanide of potassium, 417.
Cyclones, artificial, 448.

D.

Daniell (*see* Cells).
Decomposition cell, actions in, 368.
—— —— a condenser, 367.
Density, 56.
—— and surface, 64.
—— of current, 130, 404.
—— ——, effects of, 256.
—— ——, unit of, 405.
—— of energy, 552, 558.
Deposit, rate of, 406.
Deposited metal, characters of, 401.
Derived circuits, laws of, 278.
Diamagnetism, 113.
Dielectrics, current in, 79.
——, definition of, 15.
——, properties of, 78; table, 81.
—— *see* (Leakage, Soakage, Stress).
Dimensions, 230.
——, table of, 231.
——, formulæ of, 264.
Discharge (*see* Spark), 83.
——, experiments on, 45.
——, brush and star, 84.
Discharger, universal, 541.
Dissimulated electricity, 71.
Dissociation, 379.
Distance and force, law of, 54, 58.
—— ——, magnet and armature, 103.
—— ——, in depositing, 409.
Distillation, destructive, 373.
Distribution, electric, 62.
—— of light, 557.
Dry piles, 50.
Dual nature of electricity, 82, 87.
—— —— of magnetism, 524.
Dynamo machines (*see* Names of), 473.
——, alternating and direct, 503.
——, classification of, 503.
——, compound shunt and series, 509.
——, efficiency of, 513.
——, E M F of, 507, 509.
——, ——, constant, 509.
——, ——, sources of, 497.
——, energy, distribution of, in, 508.
——, evolution of the, 478.
——, history of, 473.
——, resistances of parts, 508, 510.
——, size, effect of, 506.
——, speed, effect of, 470, 507.
—— (*see* Armature, Field Magnets).
Dyne, unit of force, 227, 230.
—— and erg, equal energy, 260.

E.

Earth, the, a magnet, 107.
——, battery, 165.
——, capacity of, 235.
—— charge, imaginary, 235, 443.
——, circuit, nature of, 299.
——, currents, 441.
——, meaning of connecting to, 33, 35.
——, not a reservoir, 23, 35.
——, plate, 455.
—— ——, testing, 457.
Ebonite, 82.
——, protecting, 36.
——, transmits heat, 614.
——, tubes, to make, 532.

Edison's dynamo machine, 502.
Electricity and mechanics, 352.
——, nature of (*see* Dual), 16.
——, new source of, 617.
——, not convertible to heat, &c., 12, 218.
——, specific heat of, 621.
——, two conceptions blended in, 12, 459.
Electrics and non-electrics, 15, 27.
Electrodes, effect of size, 379.
——, *ions* accumulate at, 369.
——, ——, selection of, at, 371.
——, liquid surfaces as, 369.
Electrolysis, 356.
——, analogy to distillation, 373.
——, chemical work of, 367, 383.
——, —— affinity not suspended in, 369.
——, diagram of action, 175, 359.
——, direct and secondary, 370.
——, energy absorbed in, 376.
——, examples of, 375.
——, experimental apparatus, 382.
——, laws of, Faraday's, 359.
——, law, fundamental, 373.
——, terms of, 356.
——, theories of, 329.
——, work done in, 383.
Electrolytes, definitions of, 377.
—— in derived circuits, 375.
——, mixed, action on, 374.
—— need different E M F, 374.
——, solids are not, 359, 461.
——, ——, until fused, 359.
—— (*see* E M F, Counter, Water).
Electro-magnetism (*see* Magnetism), 467.
Electro-metallurgy (*see* Electrolysis), 386.
——, anodes, test working in, 424.
——, arrangement of objects, 407.
——, E M F required in, 402.
——, laws of, 400.
——, preparing objects for, 388.
Electro-meters, balance, 49.
——, torsion, 48.
——, quadrant, 47, 48.
——, ——, Thomson's, 311.
——, measure potential, 56.
—— —— of own circuit only, 65.
Electromotive force, 128.
—— apparatus, experimental, 311.
——, chemical affinity and, 342.
—— heat, effect on, 141.
Electromotive force, intrinsic energy and, 323.
—— is a form of energy, 259, 351.
—— —— energy, square root of, 264.
——, is it a force? 259.
——, measurement of, 308.
—— of cells, table, 336.
—— —— independent of size, 127, 128.
—— of + and − metals, 340.
—— ——, metals in H_2SO_4, 339.
—— ——, —— in solution, 369.
—— of nitric acid cells, 337.
——, origin of, in cells, 117, 173.
——, unit of, the Volt, 230.
E M F *counter*, 176, 369.
—— ——, action of, 365.
—— —— as a resistance, 276.
—— ——, electrolytic work as, 369.
—— —— induced, 276.
Electrophorus, action of, 30.
——, making, 16, 29.
Electroscope, gold leaf, 18.
—— ——, condensing action, 71.
—— ——, Bohnenberger's, 49.
—— ——, pith ball, 21.
Electrotype, 387.
Elements, 2; table of, 319.
Endosmose, electric, 136.
Energy (*see* E M F, Transmission).
——, atomic relations of, 120.
——, capacity for, 613.
——, conservation of, 11.
——, cost of (*see* Cost).
——, definition of, 11.
——, density of, in light, 558, 560.
——, different, conveyed by equal currents, 306.
——, fixed and fluctuating, 312.
——, intrinsic or specific, 313, 315.
——, ——, of elements, table, 319.
——, potential, of stress and position, 261.
——, ——, relation to force, 265.
——, relation to matter, 312.
——, —— to force, 263.
——, unit of, the Erg, 228.
——, —— of, Joule or Joulad, 235.
Engines (*see* Energy, Motors).
Equipotential lines, 89.
Equivalent, 630.
——, electric, 324, 365.
—— notation, 8.
—— of electricity, meaning, 318.
Equivolt, unit of energy, 324, 326.

Equivolt, unit of energy, on gramme system, 343.
——, ——, why used, 325.
Erg, the unit of work, 228, 629.
——, defect of, 327.
Erg-ten, 228, 630.
Ether, the, replaces old fluids, 3.
——, theories, danger of, 24.
Evaporation and electricity, 447.
Evolution, theory, 477.

F.

Falling bodies, laws of, 262.
Farad, the unit of capacity, 235.
Faraday, on force of lightning, 457.
Ferranti, dynamo machine, 502.
Field of force, action in, 482.
——, magnetic, 99.
——, —— displacement, 473.
——, mechanical imitations of, 102.
——, resistance to crossing, 471.
—— magnets, forms of, 489.
——, displacement of poles of, 491.
——, laws of, 503.
Flames and discharge, 46.
——, temperatures of, 553.
Fluid theories, 23.
—— ——, absurdities of, 26.
Fluorescence, 551.
Foot-pound, value in ergs, 228.
Force (*see* E M F, Mechanico-motive).
——, definition of, 9, 259.
——, general views of, 57, 260.
——, lines and rings of (*see* Field), 486.
——, static and dynamic, 260.
——, units of (*see* Dyne), meaning of, 263.
Forces, relation to matter, 120.
Foucault currents, 494.
Friction, how it produces electricity, 27.
Frictional machines, 36.
Fuel, energy of, 519.
Fumes in batteries, to avoid, 168.
Fusion and electricity, 221.
—— points, table of, 219.

G.

g, symbol of gravity, 263.
Galvanometer (*see* Needles), 190, 195.
——, constant of, 628.
——, correction for earth's magnetism, 199.
——, deflections, valuing, 198, 201, 217.
Galvanometer, differential, 211.
——, graduation, curves of, 206.
——, —— for depositing, 385.
—— potential or E M F, 282.
——, resistance indicating, 207.
——, —— of, to measure, 282.
——, —— —— proper, 214.
——, sine, 203.
——, Sprague's universal, 208.
——, ——, rough form of, 208.
——, stand for, 195.
—— suited to bridge work, 248.
——, tangent, 200.
——, ——, laws of, 201.
——, Thomson's reflector, 212.
——, vertical, 210.
——, wires of, influence of position, 204.
Gas, as fuel, 520.
——, energy of, 520.
——, light from, 554.
——, the share panic, 558.
——, volume and valency, 361.
—— ——, laws of, 364.
Gases, absorption heat of, 320.
——, E M F of occlusion, 618.
——, relation of, to energy, 613.
——, secondary battery, loss of, 183.
——, unit volume of, 217.
Gasification, latent energy of, 335.
Gauge (*see* Wires).
Gauss, the unit magnetic field, 109.
German silver (*see* Wires), 296.
—— ——, when to be used in galvanometers, 214.
Gilding (*see* Colour), 426.
Glass, qualities of, 36, 82.
——, absorption of light by, 555.
——, moisture on, 18.
Glue, marine, 395.
Gordon's dynamo machine, 502.
Gower's transmitter, 605.
Gramme dynamo machine, 493.
—— armature (*see* Armature, Ring), 493.
—— ——, principles of, 494.
Gravitation and electric charges, 445.
——, nature of, 261.
Gravity, force of, 227, 263.
—— ——, law of, 228; table, 263.
——, symbol *g*, value of, 263.
——, specific, table of, 219.
Gutta-percha, 82.
—— —— moulds, 394.

H.

H, magnetic symbol, 199.
Head of water, 264.
——, compared to potential, 264.
——, square root of, law, 264.
Heat, atomic and molecular, 570 (*see* Energy, E M F, Resistance).
——, convection of, 302.
——, dissipation of, 300, 302.
——, effects in batteries, 155.
—— —— in wires, 219.
——, mechanical equivalent of, 313.
——, —— work of, Favre, 277.
—— of current, 236.
—— of solution, 321.
—— rays converted to light, 565.
——, relation of, to matter, 10.
——, specific, 219, 285.
Helices, right and left handed, 466, 485.
——, theory of action, 485.
Holz machine, 47.
Homologous series, 477.
Hopkinson's dynamo, 502.
Horizontal intensity, earth, 108.
—— ——, H, value of, 199.
Horse-power, meaning of, 519, 631.
Hughes on molecular state of steel, 99.
Hydraulic analogies (*see* Current, Head).
—— laws, why different from electrical, 350.
Hydrochloric acid, 126.
—— ——, use in batteries, 146, 148.
—— ——, electrolysis of, 372.
Hydrogen a metal, 115.
——, unit volume of, 217.

I.

Incandescent lighting, 570.
—— ——, advantages of, 579.
—— lamps, carbon first used in, 574.
—— ——, form and sources of, 575.
—— ——, duration of, 579.
—— ——, early, 572.
—— ——, efficiency of, 577.
—— ——, energy per candle, 578.
Inch, cubic, of water, &c., 217, 288.
Independent (*see* Interdependence).
Index, notation, 228.
Induced charge, 66.
—— cylinders, 68.
—— currents (*see* Currents), 465.
Induction and charge, 58.
—— and energy, 67.
——, effect on telephones, 601, 602.
——, polar, 88.
——, ——, is dual, 91.
—— balance, Hughes', 615.
—— machines, 39.
—— ——, theory of, 40, 44.
Inductive circuit, 76.
—— action of currents, 462, 484.
Inductophone, W. Smith's, 614.
Inserts, depositing on, 398.
Insulation of coils, 532.
Insulating materials, 82.
—— ——, spec. resistance of, 298.
—— stand and holder, 17.
Insulite, 93.
Intensity (*see* Magnet) of current, 226, 256.
Interdependence of all things, 481, 607.
Ions, classification of, 120.
—— not transferred, 369, 381.
Iron, amalgamating, 428.
——, depositing, 432.
——, —— copper on, 435.
——, —— silver on, 421.
—— in batteries, bad, 151.
——, magnets of cast, 106.
—— wire, data of, 296.
—— ——, why bad for conductors, 301.

J.

Jars (*see* Leyden, Porous).
Joule or Joulad, unit of energy, 235, 323.
——, as unit of E M F, 354.

L.

Ladd's dynamo machine, 476.
Law, meaning of, in science, 29.
Lamps (*see* Arc, Incandescent).
Lead sulphate, reduction of, 179.
——, thickness for secondary cell, 181.
Leads (*see* Conductors, Wires).
Leakage in dielectrics, 79, 463.
Lenz's law of induction, 466.
Leyden jar, 51, 74.
Light (*see* Distribution, Photometry).
——, all sources identical, 559.
——, an octave of wave-length, 551.
—— and electricity, same velocity, 87.

Light, Clerk Maxwell's theory of, 445.
——, effect on resistance, 274.
——, energy is the source of, 559.
—— has no actual existence, 548.
——, mechanical equivalent, 552.
——, nature of, 549.
——, refractive index and dielectrics, 78.
——, units of, candles, 555.
——, why electricity produces, 553.
——, electric (*see* Arc, Incandescent).
——, ——, cost of, 577, 580.
——, ——, energy in, 577.
——, ——, history of, 558.
——, ——, ratio to current and energy, 580.
Lightning affects magnets, 107.
—— ball, 450.
——, cause of, striking, 449.
—— covers a large area, 452.
—— conductors, principles, 454.
—— ——, earths for, 455.
—— ——, not to be insulated, 456.
—— ——, testing, 457.
——, death by, painless, 453.
——, distance of, 451.
——, E M F of, 86.
——, energy in water and, 457.
—— flash, length and duration of, 451.
——, lateral discharge of, 453.
——, light of, 452.
——, marks caused by, 453.
——, sheet, 449.
Lines and rings of force, 486.
—— of force, cutting, 470.
Liquids, law of conduction in, 297.
——, resistance of, table, 298.
——, ——, apparatus for measuring, 299.
Local action, 124.
Lodge, Dr. O., on electric charge, 21.
Logarithms, value of, 287.

M.

Machines, friction, 36.
——, induction, Voss, 41.
——, ——, Wimshurst, 618.
Magnetic attraction, 101, 103.
—— capacity, 111, 527.
—— —— of various irons, 110, 527.
—— curve, 93.
—— dip, 108.
—— field, 94, 468 (*see* Field).
Magnetic field, unit, the Gauss, 10
—— induction, greatest at mid 468.
—— intensity (*see* Horizontal), 5
—— ——, changes of strength, 10
—— moment, 119.
—— needles (*see* Needles).
—— rings around conductors, 484.
—— (*see* Poles, Saturation).
—— storms, 112, 442.
——, theory, Ampère's, 97.
——, ——, molecular, 98.
—— variation, 107, 199.
—— work as resistance, 277, 539.
Magnetisation processes, 104.
—— for needles, 191.
Magnetism, analogy to charge, 463.
—— a static force, 95.
—— at right angles to electricity, 9 483.
—— effect of distance, 93.
—— —— of heat, 107.
—— —— intervening bodies, 93.
——, terrestrial, 107.
——, ——, Prof. Ayrton and Perr theory, 443.
Magnets and currents, 95, 467, 482.
——, affected by heat and lightni 107.
——, bar and horseshoe, relation, 47
——, form and construction, 106.
——, iron, cast, for, 106.
——, Jamin's, 106.
——, lifting power of, 525, 527.
——, molecular construction of, 94.
——, preservation of, 106.
——, steel, qualities for, 105.
——, electro, 523.
——, ——, formulæ of, 529.
——, ——, wires for, size of, 528.
——, ——, work of, laws, 528.
Magnetophone, 609.
Materials, cost of, table, 170.
Mathematical proofs, 443.
Matter, 1.
Measurement, 190.
—— by chemical voltameters, 215.
—— by heat calorimeters, 218.
—— by magnetic galvanometers, 190.
——, the atom, nature's unit of, 224.
Mechanical equivalent of heat, 313.
—— ——, none possible of light, 552.
Mechanico-motive force, 260, 265.
Medical action of coils, 545.
Meg, meaning as affix, 229.

Metals, to dissolve away, 392.
Melting-points of metals, 219.
Mercury, connection to zincs, 130.
——, contact breaker, 536.
——, cups and connections, 167.
——, economy in use of, 124.
Meriten's dynamo-machine, 480.
Meters for electricity, 221.
Micro, meaning of affix, 229.
—— farad of capacity, 235.
Microphone, Hughes', 602.
Microtasimeter, Edison's, 617.
Molecular chain, 333.
—— —— and E M F, 350.
—— motion, Tyndall on, 25.
—— order due to sum of forces, 482.
—— theory of electricity, 24.
—— types, 5, 122.
Molecules, 4.
——, classes of, 8.
——, solar system compared to, 8.
——, typical construction of, 122.
Moment (*see* Magnetism), 109.
Momentum, 263.
Moon and earth's magnetism, 442.
Motion, effect of, in depositing, 412.
Motograph, Edison's, 586.
Motors, electro-magnetic, 514.
——, cost of work by, 518, 521.
——, efficiency of, 517.
——, various makers of, 492, 515.
Moulds, elastic, 397.
——, fusible metal, 393.
——, plaster and composition, 393.
Musical instruments, electric, 585.
—— notes, nature of, 549, 612.

N.

Nascent actions, 372.
Needles for galvanometers, 191.
——, magnetising, 191.
——, mounting of, 192.
——, shape of, 193.
——, strength of, and deflections, 194.
——, swings of, law, 193.
Negative plate, actions at, 334, 341.
Nickel plating, 429.
Nitric acid, electrolysis of, 145.
—— ——, strengths of, 145.
—— ——, effect on E M F, 337.
Nitrogen, chloride of, 373.
Notation, chemical, 8.
——, index, 228.

O.

Occlusion of gases, 173, 174, 184.
——, E M F of, 618.
Ohm, the, unit of resistance, 232.
——, different values for, 233.
—— standard, suggested form, 234.
Ohm's formulæ and laws, 234, 257, 633.
—— —— as related to mechanics, 256.
—— —— —— to energy, 266, 354.
—— —— —— square root of energy, 266.
Organ, electric, 585.
Osmose, 633.
Oxidants, action of, in cells, 337.
Ozokerit, 82.
Ozone, nature of, 362.
—— produced by machines, 36.
—— —— in electrolysis, 378.
—— —— in secondary cells, 184.

P.

Pacinotti's ring, 476.
Pail experiment, Faraday's, 66.
Palladium absorbing hydrogen, 173.
Paraffin, many uses of, 83.
——, tendency to crack, 83.
——, wood saturated with, 18.
Peltier effect, 634.
Pendulum, law of, 193, 548.
Peroxides, depositing, 383.
Phlogiston and potential energy, 11, 316.
Phonautograph, Scott's, 591.
Phonograph, Edison's, 591.
Photometry, 555.
Photophony, direct, 612.
——, electrical, 609.
Phototelegraphy, 615.
Physical state and energy, 116, 312.
Pipes, water, resistance of, 266.
Plaster of Paris, 395.
Planté and secondary batteries, 177.
Platinized silver, 133.
—— ——, E M F of, 340.
Platinum, chloride, making, 433.
——, depositing, 433.
Plumbago, for electrotyping, 399.
Points, action of, 63.
Polar induction, dual, 91.
——, introversion, Du Moncel's, 497.
Polarization, electric, nature of, 25.
——, —— and magnetic, difference, 92.
——, in Daniell, and coppering, 141, 369.

Polarization of plates, so-called, 368, 634.
—— set up at + metal, 368.
Poles and plates, distinction, 6, 118, 175.
——, consequent, 111.
——, electric, actions at + and –, 84.
——, magnetic, unit, 109.
——, ——, position of, 107.
——, ——, ——, not fixed, 109.
——, not necessarily equal, 524.
Porous jars, 135.
——, resistance of, 297.
Position of objects, 407.
Positive and – electricity, unlike, 84.
—— —— metals, E M F of, 339.
Potential, definitions of, 59.
——, ——, as square root of force, 60, 265.
—— ——, as pressure, 60, 246.
——, ——, as units of force concentrated on a unit quantity, 265.
——, distribution of, in circuit, 244.
——, mysteries of, 61.
—— of the atmosphere, 446.
——, ——, origin of, 447.
——, relation of, to E M F, 61.
——, ——, to energy, 265.
——, ——, to square root of energy, 60, 265.
Potentiometer, Clark's, 309.
Powders, effect of heating, 395.
Power (*see* Horse), Watt unit, 236.
Pressure, electric = potential, 244.
—— stops electrolysis of water, 378.
Proof plane, 30.
Pushes, 589.

Q.

Quantity, electro-dynamic, 122, 169.
——, electrostatic, 12, 54.
——, ——, has no existence, 55.
——, the coulomb unit of, 235.
——, magnetic, 109.
Quantities, the two, in electricity, 12, 350, 459.

R.

Radicals (*see* Ions), classification, 122.
Radiant energy, actions of, 608.
Radiometer, Crooke's, 609.
Radiophony, 607.
Rain, why it attends lightning, 448.
Reciprocals, 220.
Repulsion (*see* Attraction), experiments, 22.
——, Clerk Maxwell on, 20.
——, laws of, 54.
——, theory of, 57.
Repulsive force, none in nature, 57.
Residual charge, 80.
Resistance as a velocity, 275.
——, electrical, so-called, 129.
——, ——, is reciprocal of conducting capacity of the circuit, 267, 274.
——, ——, —— of time of unit quantity, 352.
——, ——, laws of, 275.
——, ——, modes of measuring, 243.
——, ——, specific, per cub. cent., 272, 283.
——, ——, temperature, effects on, 273.
——, ——, unit of, the ohm, 232.
——, ——, work acting as, 275, 539.
——, ——, why equal for all currents, 267.
——, *true*, means work, 267.
——, ——, how represented in ohm, 354.
—— instruments, 237.
—— ——, coils, 235.
—— ——, decimal, 239.
—— —— and bridge, 250.
—— ——, variable, construction of, 254.
Resistances, consecutive, and in arc, 278.
—— of batteries, to measure, 281.
—— of carbon, 283.
—— of dielectrics, 78.
—— of galvanometers, &c., a loss, 214.
—— ——, law of proper, 214, 528.
—— of liquids, table, 298.
—— ——, apparatus for measuring, 300.
—— of metals, table, 283 (*see* Wires).
—— in electro-metallurgy, 403.
——, regulator for, 404.
Retardation, 80, 463, 636.
Reversal of batteries, 172.
Reversing commutator, 541.
Rotation of molecules, 461.

S.

Sal-ammoniac, electrolysis, 160, 372.
Salt, action of, in cells, 338.
——, electrolysis of, 389.
Salts, theory of, 317.
Secondary batteries, 172.

Secondary batteries, acid space for, 182.
—— ——, construction, 181.
—— ——, essential action of, 179.
—— ——, formation, 178.
—— ——, ——, time of, 180.
—— ——, gases, loss of, in, 183.
—— ——, metallic solutions in, 187.
—— ——, proper uses for, 176.
—— ——, work capacity of, 189.
—— ——, working details, 188.
—— ——, Brush's, 178.
—— ——, Faure's, 185.
—— ——, Planté's, 177.
—— ——, Sutton's, 187.
Secondary wire in coils, 533.
Selenium and light, 274, 609.
——, theories of action, 610.
——, cell construction, 610.
Scales for reflectors, 213.
Science, ancient and modern, 198.
Shellac, 83.
——, solution, a conductor, 83.
Ships, action of, on wind, 450.
Shunts, law of, 279.
Siemens' core, 491.
——, dynamo machine, 498.
Silver, depositing, 420.
——, bright deposit, 424.
——, to dissolve off, 392.
Sine galvanometer, 203.
Sines, laws of, 197.
Smee's laws of electro-metallurgy, 401.
Soakage in dielectrics, 79.
Soldering wires, 547.
Solubility of salts, 413.
Solution, + and − heat of, 321.
Solutions, depositing, strength of, 401. 406.
——, ——, quality of, 413.
——, ——, spoilt, to recover, 405.
Sonometer, Hughes', 616.
Sound, nature of, 549, 608.
——, signals given by, 612.
Sounds produced by heat, 612.
Spark (*see* Discharge) coils, law of, 540.
——, duration of, 36, 45.
——, qualities of, 85.
——, spectrum of, 85.
Spectrum, the, 550.
——, gradual growth of, 552.
Spiral rotation of current, 488.
——, theory of magnetism, 98.
Sphere (*see* Capacity), enclosed, 72.
Stand, insulating, 17.
Stand, rotating, for galvanometers, 195.
Static electricity a misnomer, 15.
—— —— and heat, relations, 14.
Steel, magnetic qualities of, 527.
—— suited for magnets, 105.
—— testing by magnetism, Hughes, 99.
Stopping off, varnishes, &c., 400.
Stress in dielectrics, 31.
——, breaking down limit, 79.
Stroh's experiments, 103.
Substitution, atomic, 6.
——, specific energy of, 322.
Sulphuretted hydrogen from paraffin, 83.
Sulphuric acid, strength, &c., 126.
Sun lamp, 568.
Surfaces, action of, 33.
—— and electric distribution, 62.
——, to make conducting, 399.
Swings of needle, 193.
Switches (*see* Commutator), 590.

T.

Tangent galvanometer, 200.
——, scale and law of, 197.
Telegraphy, 583.
Telephone (*see* Transmitters), 594.
—— Bell's, construction, 57.
——, current required, 596.
——, Dolbear's, 601.
——, distance used over, 605.
——, history of, 594.
——, induction coils, use with, 600.
——, ——, static, in, 598.
——, system and circuit, 606.
Temperature (*see* Wires) and current, 304.
——, correction for, 284.
—— corresponds to wave lengths, 552.
——, table of degrees of, 553.
Tension, different views of, 58.
—— in electro-metallurgy, 405.
Terrestrial magnetism, 107.
Thermo-chemistry, 313.
—— electricity, 620.
—— piles, Clamond, Noe, 622.
Thermophone, 613.
Thomson, effect, 621.
Thunderstorm, phenomena of, 449.
Torsion, laws of, 49.
Transmission of energy, 522.
—— —— by electricity and water, 307.

Transmission of energy, high E M F, gain, 307, 523.
Transmitters, automatic telegraphic, 584.
——, photophonic, 612.
——, radiophonic, 608.
——, telephonic, 599, 602.
——, telephotographic, 615.
Trigonometry, terms of, 197.
Types, molecular, 5.

U.

Unipolar actions, supposed, 90.
Unit jar, 50.
——, natural, and system, 224.
Units, absolute, 226, 231.
——, B.A. system, practical, 225.
——, C.G.S. system, 227, 229.
——, electrical static and magnetic, 229, 636.
——, relations among, 232, 314.
——, table, relations of electrical, 239.
——, ——, general conversion of, 325.

V.

V ratio, and velocity of light, 230.
Vacuum tube experiments, 91.
Valency, 3.
—— explained, 360.
——, changes of, 361.
Vapour in air stores energy, 448.
Variation of compass, 109, 199.
Varley and accumulation principle, 40.
Varnish, electric, 18.
Velocity of electricity, 87.
—— —— and light, 230.
Vision, persistence of, 45, 451.
Vis viva, 227.
Voss machine, 41.
—— ——, current from, 46.
Volt, unit of E M F, 230.
——, possible standard, 232.
——, static pressure, 323.
Voltameters, 216.
——, battery cells as, 134, 138.
Volt-ampère, 236.
—— —— hour, 237.
Volume, atomic and molecular, 571.
Vulcanised fibre, 83.

W.

Walls, charge on, 66.
——, ——, density of, 56.
——, function of, in electricity, 33.
Water, electrolysis, E M F for, 344, 376.
——, ——, supposed cases of, 377, 379.
——, ——, under pressure, 378.
—— is not an electrolyte, 377.
——, molecular construction of, 7.
——, weight of, cubic inch, 288.
——, supposed energy stored in, 458.
Waterspouts, 448.
Watt, the unit of power, 236.
Weber unit magnetic pole, 109.
Wheatstone's (*see* Bridge) lyre, 608.
Whirl, electric, 64.
Wilde's dynamo-machine, 472, 475.
Wimshurst's machine, 618.
Winter's ring, 38.
Wires, constants and formulæ of, 289.
——, copper, data of, 291; table, 294.
——, cost of, proper ratio, 305.
——, dimensions of, 285.
——, gauges of, 286, 307.
——, German silver, data, 296.
——, ——, sizes for resistances, 241.
——, hardness and conductivity, 273.
——, heat developed in, 219, 300.
——, management of, 546.
——, platinum, heat in, 220.
——, quantity on electro-magnets, 528.
——, relation of, to covering, 529.
——, safe current in, 302, 304.
——, weight per mil-foot, 288.
Wood, to make insulating, 18.
Work (*see* Energy, Resistance).
——, internal molecular, 10, 364.
——, reduces current, 276, 539.
——, units of (*see* Erg, Joulad).
——, is as square of current, 344.

Z.

Zinc, deposit on, plate, 126.
——, E M F of, 334.
——, —— effect of copper on, 141.
—— for batteries, 125.
—— in acids, action of, 115.
——, potential energy of, 315.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, STAMFORD STREET
AND CHARING CROSS.

LIST OF BOOKS

RELATING TO

ELECTRICITY, TELEGRAPHY, THE ELECTRIC LIGHT, &c.,

PUBLISHED AND SOLD BY

E. & F. N. SPON, 16, CHARING CROSS, LONDON.

Crown 8vo, cloth, 5*s.*

Workshop Receipts (Third Series). By C. G. WARNFORD LOCK, F.L.S. Devoted mainly to Electrical and Metallurgical subjects.

18mo, boards, 2*s.*

A Handbook of the Electro-Magnetic Telegraph. By A. E. LORING, a Practical Telegrapher.

With numerous Illustrations, 8vo, cloth, 21*s.*

Electricity and the Electric Telegraph. By G. B. PRESCOTT.

With numerous Illustrations, royal 8vo, cloth, 10*s.* 6*d.*

Electricity in Theory and Practice, or the Elements of ELECTRICAL ENGINEERING. By Lieut. BRADLEY A. FISKE, U.S.N.

248 pp. and 7 Plates, 8vo, cloth, 9*s.*

Reports of the Committee on Electrical Standards appointed by the BRITISH ASSOCIATION. Revised by Sir W. THOMSON, Dr. J. P. JOULE, Professors CLERK MAXWELL and FLEEMING JENKIN. With a Report to the Royal Society on Units of Electrical Resistance, by Professor F. Jenkin. Edited by Professor FLEEMING JENKIN, F.R.S.

With Illustrations, crown 8vo, cloth, 12*s.* 6*d.*

Elementary Treatise on Electric Batteries. From the French of ALFRED NIAUDET. Translated by L. M. FISHBACK.

Oblong 8vo, cloth, 10*s.* 6*d.*

Handbook of Electrical Diagrams and Connections. By C. H. DAVIS and FRANK B. RAE.

Crown 8vo, cloth, 9*s.*

A History of Electric Telegraphy, to the Year 1837. Chiefly compiled from Original Sources, and hitherto Unpublished Documents, by J. J. FAHIE, Mem. Soc. of Tel. Engineers, and of the International Society of Electricians, Paris.

Crown 8vo, cloth, 4*s.* 6*d.*

Elements of Construction for Electro-Magnets. By COUNT TH. DU MONCEL, Membre de l'Institut de France. Translated from the French by C. J. WHARTON.

8vo, sewed, 1*s.*

Electric Lighting: its State and Progress, and its Probable INFLUENCE ON THE GAS INTERESTS. By J. T. SPRAGUE, Mem. Soc. Tel. Eng.

With 113 Engravings and Diagrams, crown 8vo, cloth, 7*s.* 6*d.*

Electricity as a Motive Power. By COUNT TH. DU MONCEL, Membre de l'Institut de France, and FRANK GERALDY, Ingénieur des Ponts et Chaussées. Translated and edited by C. J. WHARTON, Assoc. Soc. of Telegraph Engineers and Electricians.

With Woodcut Illustrations, crown 8vo, cloth, 4*s.*

Useful Information on Electric Lighting. Embodying the Rules of the Fire Risk Committee and the Electric Lighting Bill; also plain directions for the working of Electric Lamps and Dynamo-Machines. By KILLINGWORTH HEDGES, F.C.S., M. Soc. T.E., Assoc. Mem. Inst. C.E. Fourth Edition, revised and enlarged.

8vo, sewed, 1*s.*

The Supply of Electricity by Local Authorities. By KILLINGWORTH HEDGES, M. Inst. M.E.

Crown 8vo, cloth, 15*s.*

Electricity: its Theory, Sources, and Application. By JOHN T. SPRAGUE, Mem. Soc. Tel. Eng. Second Edition, Revised and Enlarged, with numerous Illustrations and Tables.

8vo, cloth, 10s. 6d.

Electric Lighting by Incandescence, and its Application to Interior Illumination. A Practical Treatise, with 96 Illustrations. By W. E. Sawyer.

285 pp., with numerous Diagrams and Tables, crown 8vo, cloth, 12s. 6d.

Electrical Tables and Formulæ for the use of Telegraph Inspectors and Operators. Compiled by Latimer Clark and Robert Sabine.

18mo, cloth, 1s. 6d.

Practical Electrical Units popularly explained. By James Swinburne, late of J. N. Swan and Co., Paris, late of Brush-Swan E.L. Co., U.S.A

126 pp., with 36 Illustrations, fcap. 8vo, cloth, 1s.; sewed, 6d.

Electro-Telegraphy. A Book for Beginners. By Frederick S. Beechey, Telegraph Engineer.

With Portrait and Wood Engravings, 8vo, cloth, 7s. 6d.

Philipp Reis, Inventor of the Telephone: a Biographical Sketch, with documentary testimony, translations of the original papers of the Inventor and contemporary publications. By Silvanus P. Thompson, B.A., D.Sc., Professor of Experimental Physics in University College, Bristol.

8vo, sewed, 8s.; large paper, 12s. 6d.

Catalogue of Books and Papers relating to Electricity, Magnetism, and the Electric Telegraph, &c. Including the Ronalds Library, compiled by Sir Francis Ronalds, F.R.S., together with a Biographical Memoir of the Author. Edited by Alfred J. Frost, Assoc. Soc. T.E., Member of the Library Association of the United Kingdom.

8vo, sewed, 1s.

Electric Lighting by Water Power. By Thos. B. Grierson, Assoc. Inst. C.E.

With 62 Illustrations, crown 8vo, cloth, 3s. 6d.

Practical Electric Lighting. By A. Bromley Holmes, Assoc. M. Inst. C.E. Second Edition.

With numerous Diagrams and Tables, crown 8vo, cloth, 3s. 6d.

The Laying and Repairing of Electric Telegraph Cables. By Capt. V. Hoskier, Royal Danish Engineers.

Second Edition, crown 8vo, cloth, 4s. 6d.

A Guide for the Electric Testing of Telegraph Cables. By Capt. V. Hoskier, Royal Danish Engineers.

Crown 8vo, cloth, 15s.

A Handbook of Electrical Testing. By H. R. Kempe, Mem. Soc. Tel. Engineers. Third Edition, Revised and Enlarged.

Royal 8vo, cloth, 16s.

Lightning Conductors: their History, Nature, and Mode of Application. By R. Anderson, F.C.S., F.G.S., Member of the Society of Telegraph Engineers.

8vo, cloth, 7s. 6d.

Lightning-Rod Conference. Report of the Delegates from the following Societies, viz.: the Meteorological Society, the Royal Institute of British Architects, the Society of Telegraph Engineers and Electricians, the Physical Society, and co-opted Members. Edited by G. J. Symonds, F.R.S.

Royal 8vo, cloth, 15s.

The Speaking Telephone, Electric Light, and other Electrical Inventions. By G. B. Prescott. Fully illustrated.

Crown 8vo, cloth, 5s.

Practical Information for Telephonists. By T. D. Lockwood.

Crown 8vo, sewed, 1s.

On some New Forms of Work-Measuring Machines, as applied to Dynamos and Electro-Motors. By F. J. Smith, B.A., Assoc. Soc. Tel. Engineers, Mem. Phy. Soc. London.

18mo, boards, 2s.

Incandescent Electric Lights. With particular reference to the Edison Lamps at the Paris Exhibition. By Count du Moncel and W. H. Preece.

London: E. & F. N. SPON, 16, Charing Cross.
New York: 35, Murray Street.

ELECTRICITY:

ITS THEORY, SOURCES, AND APPLICATIONS.

By JOHN T. SPRAGUE,

MEMBER OF THE SOCIETY OF TELEGRAPH ENGINEERS AND ELECTRICIANS.

OPINIONS OF THE PRESS.

"It is quite refreshing to read a really new book on electricity . . . remarkably clear and explicit . . . gives sound, clear, and very practical directions for the manipulation of instruments. . . . Electric measurements of all kinds complete a decided addition to our electric literature."—*Telegraphic Journal.*

"Contains the fullest and most exhaustive description of the various forms of battery yet published. The tables giving the work and constancy of cells, and especially the relative working cost of the different batteries, will be found of the greatest use to the student of electric science. The chapter on Electro-Metallurgy . . . the very clearest and most complete exposition of the subject."—*English Mechanic.*

"The author has evidently been at no little pains to collect the numerous tables he gives. . . . There is also a freshness and originality in the treatment of the sections on resistance and electromotive force."—*Nature.*

"There is one thing which strikes the reader of this book at once, and more so still as he proceeds; it is the enthusiasm of Mr. Sprague's teaching. . . . Mr. Sprague has kept his views and explanations thoroughly well up with the time, and the student who has mastered his work will have no difficulty to follow well the progress of new discovery and any future extension of theories."—*Westminster Review.*

"Mr. Sprague gets through the whole of his book without any obvious effort to exhibit his own cleverness; and the student is consequently presented directly to the subject, and thereby obtains much information from few words."—*Iron.*

"The book bears evidence of much thought. . . . It is often eminently suggestive."—*Quarterly Journal of Science.*

"This author possesses the enviable faculty of making his expositions of electrical phenomena and principles clear and intelligible, and he often suggests new and valuable thoughts by his original way of handling his subject."—*Electrical World* (American).

"The principles of the science, and the operations of its laws are given with a perspicuity and fullness of exposition rarely to be met with. It is not too much to say that the laws of the correlation of the forces are here worked out in a manner exceptionally impressed with originality. . . . The work is pregnant of valuable thought and should be read by all who seek to get a firm grasp upon the fundamental principles of the science."—*Professor T. Roberts, University of South Carolina.*

1885.

BOOKS RELATING
TO
APPLIED SCIENCE
PUBLISHED BY
E. & F. N. SPON,
LONDON: 125, STRAND.

NEW YORK: 35, MURRAY STREET.

◆

A Pocket-Book for Chemists, Chemical Manufacturers, Metallurgists, Dyers, Distillers, Brewers, Sugar Refiners, Photographers, Students, etc., etc. By THOMAS BAYLEY, Assoc. R.C. Sc. Ireland, Analytical and Consulting Chemist and Assayer. Third edition, with additions, 437 pp., royal 32mo, roan, gilt edges, 5*s.*

SYNOPSIS OF CONTENTS:

Atomic Weights and Factors—Useful Data—Chemical Calculations—Rules for Indirect Analysis—Weights and Measures—Thermometers and Barometers—Chemical Physics—Boiling Points, etc.—Solubility of Substances—Methods of Obtaining Specific Gravity—Conversion of Hydrometers—Strength of Solutions by Specific Gravity—Analysis—Gas Analysis—Water Analysis—Qualitative Analysis and Reactions—Volumetric Analysis—Manipulation—Mineralogy—Assaying—Alcohol—Beer—Sugar—Miscellaneous Technological matter relating to Potash, Soda, Sulphuric Acid, Chlorine, Tar Products, Petroleum, Milk, Tallow, Photography, Prices, Wages, Appendix, etc., etc.

The Mechanician: A Treatise on the Construction and Manipulation of Tools, for the use and instruction of Young Engineers and Scientific Amateurs, comprising the Arts of Blacksmithing and Forging; the Construction and Manufacture of Hand Tools, and the various Methods of Using and Grinding them; the Construction of Machine Tools, and how to work them; Machine Fitting and Erection; description of Hand and Machine Processes; Turning and Screw Cutting; principles of Constructing and details of Making and Erecting Steam Engines, and the various details of setting out work, etc., etc. By CAMERON KNIGHT, Engineer. *Containing* 1147 *illustrations,* and 397 pages of letter-press. Third edition, 4to, cloth, 18*s.*

On Designing Belt Gearing. By E. J. COWLING WELCH, Mem. Inst. Mech. Engineers, Author of 'Designing Valve Gearing.' Fcap. 8vo, sewed, 6*d.*

A Handbook of Formulæ, Tables, and Memoranda, for Architectural Surveyors and others engaged in Building. By J. T. HURST, C.E. Thirteenth edition, royal 32mo, roan, 5*s.*

"It is no disparagement to the many excellent publications we refer to, to say that in our opinion this little pocket-book of Hurst's is the very best of them all, without any exception. It would be useless to attempt a recapitulation of the contents, for it appears to contain almost *everything* that anyone connected with building could require, and, best of all, made up in a compact form for carrying in the pocket, measuring only 5 in. by 3 in., and about ¾ in. thick, in a limp cover. We congratulate the author on the success of his laborious and practically compiled little book, which has received unqualified and deserved praise from every professional person to whom we have shown it."—*The Dublin Builder.*

Tabulated Weights of Angle, Tee, Bulb, Round, Square, and Flat Iron and Steel, and other information for the use of Naval Architects and Shipbuilders. By C. H. JORDAN, M.I.N.A. Fourth edition, 32mo, cloth, 2*s.* 6*d.*

Quantity Surveying. By J. LEANING. With 42 illustrations, crown 8vo, cloth, 9*s.*

CONTENTS:

A complete Explanation of the London Practice.
General Instructions.
Order of Taking Off.
Modes of Measurement of the various Trades.
Use and Waste.
Ventilation and Warming.
Credits, with various Examples of Treatment.
Abbreviations.
Squaring the Dimensions.
Abstracting, with Examples in illustration of each Trade.
Billing.
Examples of Preambles to each Trade.
Form for a Bill of Quantities.
Do. Bill of Credits.
Do. Bill for Alternative Estimate.
Restorations and Repairs, and Form of Bill.
Variations before Acceptance of Tender.
Errors in a Builder's Estimate.
Schedule of Prices.
Form of Schedule of Prices.
Analysis of Schedule of Prices.
Adjustment of Accounts.
Form of a Bill of Variations.
Remarks on Specifications.
Prices and Valuation of Work, with Examples and Remarks upon each Trade.
The Law as it affects Quantity Surveyors, with Law Reports.
Taking Off after the Old Method.
Northern Practice.
The General Statement of the Methods recommended by the Manchester Society of Architects for taking Quantities.
Examples of Collections.
Examples of "Taking Off" in each Trade.
Remarks on the Past and Present Methods of Estimating.

A Practical Treatise on Heat, as applied to the Useful Arts; for the Use of Engineers, Architects, &c. By THOMAS BOX. *With* 14 *plates.* Third edition, crown 8vo, cloth, 12*s.* 6*d.*

A Descriptive Treatise on Mathematical Drawing Instruments: their construction, uses, qualities, selection, preservation, and suggestions for improvements, with hints upon Drawing and Colouring. By W. F. STANLEY, M.R.I. Fifth edition, *with numerous illustrations,* crown 8vo, cloth, 5*s.*

Spons' Architects' and Builders' Pocket-Book of Prices and Memoranda. Edited by W. YOUNG, Architect. Royal 32mo, roan, 4*s.* 6*d.*; or cloth, red edges, 3*s.* 6*d.* *Published annually.* Eleventh edition. *Now ready.*

Long-Span Railway Bridges, comprising Investigations of the Comparative Theoretical and Practical Advantages of the various adopted or proposed Type Systems of Construction, with numerous Formulæ and Tables giving the weight of Iron or Steel required in Bridges from 300 feet to the limiting Spans; to which are added similar Investigations and Tables relating to Short-span Railway Bridges. Second and revised edition. By B. BAKER, Assoc. Inst. C.E. *Plates*, crown 8vo, cloth, 5*s.*

Elementary Theory and Calculation of Iron Bridges and Roofs. By AUGUST RITTER, Ph.D., Professor at the Polytechnic School at Aix-la-Chapelle. Translated from the third German edition, by H. R. SANKEY, Capt. R.E. With 500 *illustrations*, 8vo, cloth, 15*s.*

The Builder's Clerk: a Guide to the Management of a Builder's Business. By THOMAS BALES. Fcap. 8vo, cloth, 1*s.* 6*d.*

The Elementary Principles of Carpentry. By THOMAS TREDGOLD. Revised from the original edition, and partly re-written, by JOHN THOMAS HURST. Contained in 517 pages of letterpress, and *illustrated with* 48 *plates and* 150 *wood engravings.* Third edition, crown 8vo, cloth, 18*s.*

Section I. On the Equality and Distribution of Forces—Section II. Resistance of Timber—Section III. Construction of Floors—Section IV. Construction of Roofs—Section V. Construction of Domes and Cupolas—Section VI. Construction of Partitions—Section VII. Scaffolds, Staging, and Gantries—Section VIII. Construction of Centres for Bridges—Section IX. Coffer-dams, Shoring, and Strutting—Section X. Wooden Bridges and Viaducts—Section XI. Joints, Straps, and other Fastenings—Section XII. Timber.

Our Factories, Workshops, and Warehouses: their Sanitary and Fire-Resisting Arrangements. By B. H. THWAITE, Assoc. Mem. Inst. C.E. *With* 183 *wood engravings*, crown 8vo, cloth, 9*s.*

Gold: Its Occurrence and Extraction, embracing the Geographical and Geological Distribution and the Mineralogical Characters of Gold-bearing rocks; the peculiar features and modes of working Shallow Placers, Rivers, and Deep Leads; Hydraulicing; the Reduction and Separation of Auriferous Quartz; the treatment of complex Auriferous ores containing other metals; a Bibliography of the subject and a Glossary of Technical and Foreign Terms. By ALFRED G. LOCK, F.R.G.S. *With numerous illustrations and maps*, 1250 pp., super-royal 8vo, cloth, 2*l.* 12*s.* 6*d.*

A Practical Treatise on Coal Mining. By GEORGE G. ANDRÉ, F.G.S., Assoc. Inst. C.E., Member of the Society of Engine *With* 82 *lithographic plates.* 2 vols., royal 4to, cloth, 3*l.* 12*s.*

Iron Roofs: Examples of Design, Description. *Illustrated with* 64 *Working Drawings of Executed Roofs.* By ARTHUR T. WALMISLEY, Assoc. Mem. Inst. C.E. Imp. 4to, half-morocco, £2 12*s.* 6

A History of Electric Telegraphy, to the Year 1837. Chiefly compiled from Original Sources, and hitherto Unpublished Documents, by J. J. FAHIE, Mem. Soc. of Tel. Engineers, and of the International Society of Electricians, Paris. Crown 8vo, cloth, 9*s.*

Spons' Information for Colonial Engineers. Edited by J. T. HURST. Demy 8vo, sewed.

No. 1, Ceylon. By ABRAHAM DEANE, C.E. 2*s.* 6*d.*

CONTENTS:

Introductory Remarks — Natural Productions — Architecture and Engineering — Topography, Trade, and Natural History—Principal Stations—Weights and Measures, etc., etc.

No. 2. Southern Africa, including the Cape Colony, Natal, and the Dutch Republics. By HENRY HALL, F.R.G.S., F.R.C.I. With Map. 3*s.* 6*d.*

CONTENTS:

General Description of South Africa—Physical Geography with reference to Engineering Operations—Notes on Labour and Material in Cape Colony—Geological Notes on Roc Formation in South Africa—Engineering Instruments for Use in South Africa—Princip Public Works in Cape Colony: Railways, Mountain Roads and Passes, Harbour Work Bridges, Gas Works, Irrigation and Water Supply, Lighthouses, Drainage and Sanit Engineering, Public Buildings, Mines—Table of Woods in South Africa—Animals used f Draught Purposes—Statistical Notes—Table of Distances—Rates of Carriage, etc.

No. 3. India. By F. C. DANVERS, Assoc. Inst. C.E. With Map. 4*s.* 6*d*

CONTENTS:

Physical Geography of India—Building Materials—Roads—Railways—Bridges—Irrigation — River Works — Harbours — Lighthouse Buildings — Native Labour — The Princip Trees of India—Money—Weights and Measures—Glossary of Indian Terms, etc.

A Practical Treatise on Casting and Founding including descriptions of the modern machinery employed in the art. B N. E. SPRETSON, Engineer. Third edition, with 82 *plates* drawn t scale, 412 pp., demy 8vo, cloth, 18*s.*

Steam Heating for Buildings; or, Hints to Steam Fitters, being a description of Steam Heating Apparatus for Warming and Ventilating Private Houses and Large Buildings, with remarks on Steam, Water, and Air in their relation to Heating. By W. J. BALDWIN. *With many illustrations.* Fourth edition, crown 8vo, cloth, 10*s.* 6*d.*

The Depreciation of Factories and their Valuation. By EWING MATHESON, M. Inst. C.E. 8vo, cloth, 6*s.*

A Handbook of Electrical Testing. By H. R. KEMPE, M.S.T.E. Third edition, revised and enlarged, crown 8vo, cloth, 15*s.*

Gas Works: their Arrangement, Construction, Plant, and Machinery. By F. COLYER, M. Inst. C.E. *With* 31 *folding plates,* 8vo, cloth, 24*s.*

The Clerk of Works: a Vade-Mecum for all engaged in the Superintendence of Building Operations. By G. G. HOSKINS, F.R.I.B.A. Third edition, fcap. 8vo, cloth, 1*s.* 6*d.*

American Foundry Practice: Treating of Loam, Dry Sand, and Green Sand Moulding, and containing a Practical Treatise upon the Management of Cupolas, and the Melting of Iron. By T. D. WEST, Practical Iron Moulder and Foundry Foreman. Second edition, *with numerous illustrations,* crown 8vo, cloth, 10*s.* 6*d.*

The Maintenance of Macadamised Roads. By T. CODRINGTON, M.I.C.E, F.G.S., General Superintendent of County Roads for South Wales. 8vo, cloth, 6*s.*

Hydraulic Steam and Hand Power Lifting and Pressing Machinery. By FREDERICK COLYER, M. Inst. C.E., M. Inst. M.E. *With* 73 *plates,* 8vo, cloth, 18*s.*

Pumps and Pumping Machinery. By F. COLYER, M.I.C.E., M.I.M.E. *With* 23 *folding plates,* 8vo, cloth, 12*s.* 6*d.*

The Municipal and Sanitary Engineer's Handbook. By H. PERCY BOULNOIS, Mem. Inst. C.E., Borough Engineer, Portsmouth. *With numerous illustrations,* demy 8vo, cloth, 12*s.* 6*d.*

CONTENTS:

The Appointment and Duties of the Town Surveyor—Traffic—Macadamised Roadways—Steam Rolling—Road Metal and Breaking—Pitched Pavements—Asphalte—Wood Pavements—Footpaths—Kerbs and Gutters—Street Naming and Numbering—Street Lighting—Sewerage—Ventilation of Sewers—Disposal of Sewage—House Drainage—Disinfection—Gas and Water Companies, &c., Breaking up Streets—Improvement of Private Streets—Borrowing Powers—Artizans' and Labourers' Dwellings—Public Conveniences—Scavenging, including Street Cleansing—Watering and the Removing of Snow—Planting Street Trees—Deposit of Plans—Dangerous Buildings—Hoardings—Obstructions—Improving Street Lines—Cellar Openings—Public Pleasure Grounds—Cemeteries—Mortuaries—Cattle and Ordinary Markets—Public Slaughter-houses, etc.—Giving numerous Forms of Notices, Specifications, and General Information upon these and other subjects of great importance to Municipal Engineers and others engaged in Sanitary Work.

Tables of the Principal Speeds occurring in Mechanica Engineering, expressed in metres in a second. By P. KEERAYEFF, Chie Mechanic of the Obouchoff Steel Works, St. Petersburg; translated b SERGIUS KERN, M.E. Fcap. 8vo, sewed, 6*d.*

A Treatise on the Origin, Progress, Prevention, an Cure of Dry Rot in Timber; with Remarks on the Means of Preservin Wood from Destruction by Sea-Worms, Beetles, Ants, etc. By THOMA ALLEN BRITTON, late Surveyor to the Metropolitan Board of Work etc., etc. *With* 10 *plates*, crown 8vo, cloth, 7*s.* 6*d.*

Metrical Tables. By G. L. MOLESWORTH, M.I.C.E. 32mo, cloth, 1*s.* 6*d.*

CONTENTS.

General—Linear Measures—Square Measures—Cubic Measures—Measures of Capacity—Weights—Combinations—Thermometers.

Elements of Construction for Electro-Magnets. By Count TH. DU MONCEL, Mem. de l'Institut de France. Translated from the French by C. J. WHARTON. Crown 8vo, cloth, 4*s.* 6*d.*

Electro-Telegraphy. By FREDERICK S. BEECHEY, Telegraph Engineer. A Book for Beginners. *Illustrated.* Fcap. 8vo, sewed, 6*d.*

Handrailing: by the Square Cut. By JOHN JONES, Staircase Builder. Fourth edition, *with seven plates*, 8vo, cloth, 3*s.* 6*d.*

Handrailing: by the Square Cut. By JOHN JONES, Staircase Builder. Part Second, *with eight plates*, 8vo, cloth, 3*s.* 6*d.*

Practical Electrical Units Popularly Explained, with *numerous illustrations* and Remarks. By JAMES SWINBURNE, late of J. W. Swan and Co., Paris, late of Brush-Swan Electric Light Company, U.S.A. 18mo, cloth, 1*s.* 6*d.*

Philipp Reis, Inventor of the Telephone: A Biographical Sketch. With Documentary Testimony, Translations of the Original Papers of the Inventor, &c. By SILVANUS P. THOMPSON, B.A., Dr. Sc., Professor of Experimental Physics in University College, Bristol. *With illustrations*, 8vo, cloth, 7*s.* 6*d.*

A Treatise on the Use of Belting for the Transmission of Power. By J. H. COOPER. Second edition, *illustrated*, 8vo, cloth, 15*s.*

A Pocket-Book of Useful Formulæ and Memoranda for Civil and Mechanical Engineers. By **Guilford L. Molesworth**, Mem. Inst. C.E., Consulting Engineer to the Government of India for State Railways. *With numerous illustrations*, 744 pp., Twenty-first edition, revised and enlarged, 32mo, roan, 6*s.*

SYNOPSIS OF CONTENTS:

Surveying, Levelling, etc.—Strength and Weight of Materials—Earthwork, Brickwork, Masonry, Arches, etc.—Struts, Columns, Beams, and Trusses—Flooring, Roofing, and Roof Trusses—Girders, Bridges, etc.—Railways and Roads—Hydraulic Formulæ—Canals, Sewers, Waterworks, Docks—Irrigation and Breakwaters—Gas, Ventilation, and Warming—Heat, Light, Colour, and Sound—Gravity: Centres, Forces, and Powers—Millwork, Teeth of Wheels, Shafting, etc.—Workshop Recipes—Sundry Machinery—Animal Power—Steam and the Steam Engine—Water-power, Water-wheels, Turbines, etc.—Wind and Windmills—Steam Navigation, Ship Building, Tonnage, etc.—Gunnery, Projectiles, etc.—Weights, Measures, and Money—Trigonometry, Conic Sections, and Curves—Telegraphy—Mensuration—Tables of Areas and Circumference, and Arcs of Circles—Logarithms, Square and Cube Roots, Powers—Reciprocals, etc.—Useful Numbers—Differential and Integral Calculus—Algebraic Signs—Telegraphic Construction and Formulæ.

Spons' Tables and Memoranda for Engineers; selected and arranged by J. T. **Hurst**, C.E., Author of 'Architectural Surveyors' Handbook,' 'Hurst's Tredgold's Carpentry,' etc. Fifth edition, 64mo, roan, gilt edges, 1*s.*; or in cloth case, 1*s.* 6*d.*

This work is printed in a pearl type, and is so small, measuring only 2½ in. by 1¼ in. by ¼ in. thick, that it may be easily carried in the waistcoat pocket.

"It is certainly an extremely rare thing for a reviewer to be called upon to notice a volume measuring but 2½ in. by 1¼ in., yet these dimensions faithfully represent the size of the handy little book before us. The volume—which contains 118 printed pages, besides a few blank pages for memoranda—is, in fact, a true pocket-book, adapted for being carried in the waistcoat pocket, and containing a far greater amount and variety of information than most people would imagine could be compressed into so small a space. . . . The little volume has been compiled with considerable care and judgment, and we can cordially recommend it to our readers as a useful little pocket companion."—*Engineering.*

A Practical Treatise on Natural and Artificial Concrete, its Varieties and Constructive Adaptations. By **Henry Reid**, Author of the 'Science and Art of the Manufacture of Portland Cement.' New Edition, *with* 59 *woodcuts and* 5 *plates*, 8vo, cloth, 15*s.*

Hydrodynamics: Treatise relative to the Testing of Water-Wheels and Machinery, with various other matters pertaining to Hydrodynamics. By **James Emerson**. *With numerous illustrations*, 360 pp. Third edition, crown 8vo, cloth, 4*s.* 6*d.*

Electricity as a Motive Power. By Count **Th. Du Moncel**, Membre de l'Institut de France, and **Frank Geraldy**, Ingénieur des Ponts et Chaussées. Translated and Edited, with Additions, by C. J. **Wharton**, Assoc. Soc. Tel. Eng. and Elec. *With* 113 *engravings and diagrams*, crown 8vo, cloth, 7*s.* 6*d.*

Hints on Architectural Draughtsmanship. By G. W. **Tuxford Hallatt**. Fcap. 8vo, cloth, 1*s.* 6*d.*

Treatise on Valve-Gears, with special consideration of the Link-Motions of Locomotive Engines. By Dr. GUSTAV ZEUNER, Professor of Applied Mechanics at the Confederated Polytechnikum of Zurich. Translated from the Fourth German Edition, by Professor J. F. KLEIN, Lehigh University, Bethlehem, Pa. *Illustrated*, 8vo, cloth, 12*s*. 6*d*.

The French-Polisher's Manual. By a French-Polisher; containing Timber Staining, Washing, Matching, Improving, Painting, Imitations, Directions for Staining, Sizing, Embodying, Smoothing, Spirit Varnishing, French-Polishing, Directions for Re-polishing. Third edition, royal 32mo, sewed, 6*d*.

Hops, their Cultivation, Commerce, and Uses in various Countries. By P. L. SIMMONDS. Crown 8vo, cloth, 4*s*. 6*d*.

A Practical Treatise on the Manufacture and Distribution of Coal Gas. By WILLIAM RICHARDS. Demy 4to, with *numerous wood engravings and* 29 *plates*, cloth, 28*s*.

SYNOPSIS OF CONTENTS:

Introduction—History of Gas Lighting—Chemistry of Gas Manufacture, by Lewis Thompson, Esq., M.R.C.S.—Coal, with Analyses, by J. Paterson, Lewis Thompson, and G. R. Hislop, Esqrs.—Retorts, Iron and Clay—Retort Setting—Hydraulic Main—Condensers—Exhausters—Washers and Scrubbers—Purifiers—Purification—History of Gas Holder—Tanks, Brick and Stone, Composite, Concrete, Cast-iron, Compound Annular Wrought-iron—Specifications—Gas Holders—Station Meter—Governor—Distribution—Mains—Gas Mathematics, or Formulæ for the Distribution of Gas, by Lewis Thompson, Esq.—Services—Consumers' Meters—Regulators—Burners—Fittings—Photometer—Carburization of Gas—Air Gas and Water Gas—Composition of Coal Gas, by Lewis Thompson, Esq.—Analyses of Gas—Influence of Atmospheric Pressure and Temperature on Gas—Residual Products—Appendix—Description of Retort Settings, Buildings, etc., etc.

Practical Geometry, Perspective, and Engineering Drawing; a Course of Descriptive Geometry adapted to the Requirements of the Engineering Draughtsman, including the determination of cast shadows and Isometric Projection, each chapter being followed by numerous examples; to which are added rules for Shading, Shade-lining, etc., together with practical instructions as to the Lining, Colouring, Printing, and general treatment of Engineering Drawings, with a chapter on drawing Instruments. By GEORGE S. CLARKE, Capt. R.E. Second edition, *with* 21 *plates*. 2 vols., cloth, 10*s*. 6*d*.

The Elements of Graphic Statics. By Professor KARL VON OTT, translated from the German by G. S. CLARKE, Capt. R.E., Instructor in Mechanical Drawing, Royal Indian Engineering College. *With* 93 *illustrations*, crown 8vo, cloth, 5*s*.

The Principles of Graphic Statics. By GEORGE SYDENHAM CLARKE, Capt. Royal Engineers. *With* 112 *illustrations*. 4to, cloth, 12*s*. 6*d*.

Dynamo-Electric Machinery: A Manual for Students of Electro-technics. By SILVANUS P. THOMPSON, B.A., D.Sc., Professor of Experimental Physics in University College, Bristol, etc., etc. *Illustrated*, 8vo, cloth, 12*s*. 6*d*.

The New Formula for Mean Velocity of Discharge of Rivers and Canals. By W. R. KUTTER. Translated from articles in the 'Cultur-Ingénieur,' by LOWIS D'A. JACKSON, Assoc. Inst. C.E. 8vo, cloth, 12*s.* 6*d.*

Practical Hydraulics; a Series of Rules and Tables for the use of Engineers, etc., etc. By THOMAS BOX. Fifth edition, *numerous plates*, post 8vo, cloth, 5*s.*

A Practical Treatise on the Construction of Horizontal and Vertical Waterwheels, specially designed for the use of operative mechanics. By WILLIAM CULLEN, Millwright and Engineer. *With* 11 *plates.* Second edition, revised and enlarged, small 4to, cloth, 12*s.* 6*d.*

Tin: Describing the Chief Methods of Mining, Dressing and Smelting it abroad; with Notes upon Arsenic, Bismuth and Wolfram. By ARTHUR G. CHARLETON, Mem. American Inst. of Mining Engineers. *With plates*, 8vo, cloth, 12*s.* 6*d.*

Perspective, Explained and Illustrated. By G. S. CLARKE, Capt. R.E. *With illustrations*, 8vo, cloth, 3*s.* 6*d.*

The Essential Elements of Practical Mechanics; based on the Principle of Work, designed for Engineering Students. By OLIVER BYRNE, formerly Professor of Mathematics, College for Civil Engineers. Third edition, *with* 148 *wood engravings*, post 8vo, cloth, 7*s.* 6*d.*

CONTENTS:

Chap. 1. How Work is Measured by a Unit, both with and without reference to a Unit of Time—Chap. 2. The Work of Living Agents, the Influence of Friction, and introduces one of the most beautiful Laws of Motion—Chap. 3. The principles expounded in the first and second chapters are applied to the Motion of Bodies—Chap. 4. The Transmission of Work by simple Machines—Chap. 5. Useful Propositions and Rules.

The Practical Millwright and Engineer's Ready Reckoner; or Tables for finding the diameter and power of cog-wheels, diameter, weight, and power of shafts, diameter and strength of bolts, etc. By THOMAS DIXON. Fourth edition, 12mo, cloth, 3*s.*

Breweries and Maltings: their Arrangement, Construction, Machinery, and Plant. By G. SCAMELL, F.R.I.B.A. Second edition, revised, enlarged, and partly rewritten. By F. COLYER, M.I.C.E., M.I.M.E. *With* 20 *plates*, 8vo, cloth, 18*s.*

A Practical Treatise on the Manufacture of Starch, Glucose, Starch-Sugar, and Dextrine, based on the German of L. Von Wagner, Professor in the Royal Technical School, Buda Pesth, and other authorities. By JULIUS FRANKEL; edited by ROBERT HUTTER, proprietor of the Philadelphia Starch Works. *With* 58 *illustrations*, 344 pp., 8vo, cloth, 18*s.*

A Practical Treatise on Mill-gearing, Wheels, Shafts, Riggers, etc.; for the use of Engineers. By **Thomas Box**. Third edition, *with* 11 *plates*. Crown 8vo, cloth, 7*s*. 6*d*.

Mining Machinery: a Descriptive Treatise on the Machinery, Tools, and other Appliances used in Mining. By **G. G. André**, F.G.S., Assoc. Inst. C.E., Mem. of the Society of Engineers. Royal 4to, uniform with the Author's Treatise on Coal Mining, containing 182 *plates*, accurately drawn to scale, with descriptive text, in 2 vols., cloth, 3*l*. 12*s*.

CONTENTS:

Machinery for Prospecting, Excavating, Hauling, and Hoisting—Ventilation—Pumping—Treatment of Mineral Products, including Gold and Silver, Copper, Tin, and Lead, Iron, Coal, Sulphur, China Clay, Brick Earth, etc.

Tables for Setting out Curves for Railways, Canals, Roads, etc., varying from a radius of five chains to three miles. By **A. Kennedy** and **R. W. Hackwood**. *Illustrated*, 32mo, cloth, 2*s*. 6*d*.

The Science and Art of the Manufacture of Portland Cement, with observations on some of its constructive applications. *With* 66 *illustrations*. By **Henry Reid**, C.E., Author of 'A Practical Treatise on Concrete,' etc., etc. 8vo, cloth, 18*s*.

The Draughtsman's Handbook of Plan and Map Drawing; including instructions for the preparation of Engineering, Architectural, and Mechanical Drawings. *With numerous illustrations in the text, and* 33 *plates* (15 *printed in colours*). By **G. G. André**, F.G.S., Assoc. Inst. C.E. 4to, cloth, 9*s*.

CONTENTS:

The Drawing Office and its Furnishings—Geometrical Problems—Lines, Dots, and their Combinations—Colours, Shading, Lettering, Bordering, and North Points—Scales—Plotting—Civil Engineers' and Surveyors' Plans—Map Drawing—Mechanical and Architectural Drawing—Copying and Reducing Trigonometrical Formulæ, etc., etc.

The Boiler-maker's and Iron Ship-builder's Companion, comprising a series of original and carefully calculated tables, of the utmost utility to persons interested in the iron trades. By **James Foden**, author of 'Mechanical Tables,' etc. Second edition revised, *with illustrations*, crown 8vo, cloth, 5*s*.

Rock Blasting: a Practical Treatise on the means employed in Blasting Rocks for Industrial Purposes. By **G. G. André**, F.G.S., Assoc. Inst. C.E. *With* 56 *illustrations and* 12 *plates*, 8vo, cloth, 10*s*. 6*d*.

Painting and Painters' Manual: a Book of Facts for Painters and those who Use or Deal in Paint Materials. By **C. L. Condit** and **J. Scheller**. *Illustrated*, 8vo, cloth, 10*s*. 6*d*.

A Treatise on Ropemaking as practised in public and private Rope-yards, with a Description of the Manufacture, Rules, Tables of Weights, etc., adapted to the Trade, Shipping, Mining, Railways, Builders, etc. By R. CHAPMAN, formerly foreman to Messrs. Huddart and Co., Limehouse, and late Master Ropemaker to H.M. Dockyard, Deptford. Second edition, 12mo, cloth, 3*s*.

Laxton's Builders' and Contractors' Tables; for the use of Engineers, Architects, Surveyors, Builders, Land Agents, and others. Bricklayer, containing 22 tables, with nearly 30,000 calculations. 4to, cloth, 5*s*.

Laxton's Builders' and Contractors' Tables. Excavator, Earth, Land, Water, and Gas, containing 53 tables, with nearly 24,000 calculations. 4to, cloth, 5*s*.

Sanitary Engineering: a Guide to the Construction of Works of Sewerage and House Drainage, with Tables for facilitating the calculations of the Engineer. By BALDWIN LATHAM, C.E., M. Inst. C.E., F.G.S., F.M.S., Past-President of the Society of Engineers. Second edition, *with numerous plates and woodcuts*, 8vo, cloth, 1*l*. 10*s*.

Screw Cutting Tables for Engineers and Machinists, giving the values of the different trains of Wheels required to produce Screws of any pitch, calculated by Lord Lindsay, M.P., F.R.S., F.R.A.S., etc. Cloth, oblong, 2*s*.

Screw Cutting Tables, for the use of Mechanical Engineers, showing the proper arrangement of Wheels for cutting the Threads of Screws of any required pitch, with a Table for making the Universal Gas-pipe Threads and Taps. By W. A. MARTIN, Engineer. Second edition, oblong, cloth, 1*s*., or sewed, 6*d*.

A Treatise on a Practical Method of Designing Slide-Valve Gears by Simple Geometrical Construction, based upon the principles enunciated in Euclid's Elements, and comprising the various forms of Plain Slide-Valve and Expansion Gearing; together with Stephenson's, Gooch's, and Allan's Link-Motions, as applied either to reversing or to variable expansion combinations. By EDWARD J. COWLING WELCH, Memb. Inst. Mechanical Engineers. Crown 8vo, cloth, 6*s*.

Cleaning and Scouring: a Manual for Dyers, Laundresses, and for Domestic Use. By S. CHRISTOPHER. 18mo, sewed, 6*d*.

A Handbook of House Sanitation; for the use of all persons seeking a Healthy Home. A reprint of those portions of Mr. Bailey-Denton's Lectures on Sanitary Engineering, given before the School of Military Engineering, which related to the "Dwelling," enlarged and revised by his Son, E. F. BAILEY-DENTON, C.E., B.A. *With 140 illustrations*, 8vo, cloth, 8*s*. 6*d*.

A Glossary of Terms used in Coal Mining. By WILLIAM STUKELEY GRESLEY, Assoc. Mem. Inst. C.E., F.G.S., Member of the North of England Institute of Mining Engineers. *Illustrated with numerous woodcuts and diagrams*, crown 8vo, cloth, 5*s.*

A Pocket-Book for Boiler Makers and Steam Users, comprising a variety of useful information for Employer and Workman, Government Inspectors, Board of Trade Surveyors, Engineers in charge of Works and Slips, Foremen of Manufactories, and the general Steam-using Public. By MAURICE JOHN SEXTON. Second edition, royal 32mo, roan, gilt edges, 5*s.*

The Strains upon Bridge Girders and Roof Trusses, including the Warren, Lattice, Trellis, Bowstring, and other Forms of Girders, the Curved Roof, and Simple and Compound Trusses. By THOS. CARGILL, C.E.B.A.T., C.D., Assoc. Inst. C.E., Member of the Society of Engineers. *With* 64 *illustrations, drawn and worked out to scale*, 8vo, cloth, 12*s.* 6*d.*

A Practical Treatise on the Steam Engine, containing Plans and Arrangements of Details for Fixed Steam Engines, with Essays on the Principles involved in Design and Construction. By ARTHUR RIGG, Engineer, Member of the Society of Engineers and of the Royal Institution of Great Britain. Demy 4to, *copiously illustrated with woodcuts and* 96 *plates*, in one Volume, half-bound morocco, 2*l.* 2*s.*; or cheaper edition, cloth, 25*s.*

This work is not, in any sense, an elementary treatise, or history of the steam engine, but is intended to describe examples of Fixed Steam Engines without entering into the wide domain of locomotive or marine practice. To this end illustrations will be given of the most recent arrangements of Horizontal, Vertical, Beam, Pumping, Winding, Portable, Semi-portable, Corliss, Allen, Compound, and other similar Engines, by the most eminent Firms in Great Britain and America. The laws relating to the action and precautions to be observed in the construction of the various details, such as Cylinders, Pistons, Piston-rods, Connecting-rods, Cross-heads, Motion-blocks, Eccentrics, Simple, Expansion, Balanced, and Equilibrium Slide-valves, and Valve-gearing will be minutely dealt with. In this connection will be found articles upon the Velocity of Reciprocating Parts and the Mode of Applying the Indicator, Heat and Expansion of Steam Governors, and the like. It is the writer's desire to draw illustrations from every possible source, and give only those rules that present practice deems correct.]

Barlow's Tables of Squares, Cubes, Square Roots, Cube Roots, Reciprocals of all Integer Numbers up to 10,000. Post 8vo, cloth, 6*s.*

Camus (M.) Treatise on the Teeth of Wheels, demonstrating the best forms which can be given to them for the purposes of Machinery, such as Mill-work and Clock-work, and the art of finding their numbers. Translated from the French, with details of the present practice of Millwrights, Engine Makers, and other Machinists, by ISAAC HAWKINS. Third edition, *with* 18 *plates*, 8vo, cloth, 5*s.*

A Practical Treatise on the Science of Land and Engineering Surveying, Levelling, Estimating Quantities, etc., with a general description of the several Instruments required for Surveying, Levelling, Plotting, etc. By H. S. MERRETT. Third edition, 41 *plates with illustrations and tables*, royal 8vo, cloth, 12*s.* 6*d.*

PRINCIPAL CONTENTS:

Part 1. Introduction and the Principles of Geometry. Part 2. Land Surveying; comprising General Observations—The Chain—Offsets Surveying by the Chain only—Surveying Hilly Ground—To Survey an Estate or Parish by the Chain only—Surveying with the Theodolite—Mining and Town Surveying—Railroad Surveying—Mapping—Division and Laying out of Land—Observations on Enclosures—Plane Trigonometry. Part 3. Levelling—Simple and Compound Levelling—The Level Book—Parliamentary Plan and Section—Levelling with a Theodolite—Gradients—Wooden Curves—To Lay out a Railway Curve—Setting out Widths. Part 4. Calculating Quantities generally for Estimates—Cuttings and Embankments—Tunnels—Brickwork—Ironwork—Timber Measuring. Part 5. Description and Use of Instruments in Surveying and Plotting—The Improved Dumpy Level—Troughton's Level—The Prismatic Compass—Proportional Compass—Box Sextant—Vernier—Pantagraph—Merrett's Improved Quadrant—Improved Computation Scale—The Diagonal Scale—Straight Edge and Sector. Part 6. Logarithms of Numbers—Logarithmic Sines and Co-Sines, Tangents and Co-Tangents—Natural Sines and Co-Sines—Tables for Earthwork, for Setting out Curves, and for various Calculations, etc., etc., etc.

Saws: the History, Development, Action, Classification, and Comparison of Saws of all kinds. By ROBERT GRIMSHAW. *With* 220 *illustrations*, 4to, cloth, 12*s.* 6*d.*

A Supplement to the above; containing additional practical matter, more especially relating to the forms of Saw Teeth for special material and conditions, and to the behaviour of Saws under particular conditions. *With* 120 *illustrations*, cloth, 9*s.*

A Guide for the Electric Testing of Telegraph Cables. By Capt. V. HOSKIŒR, Royal Danish Engineers. *With illustrations*, second edition, crown 8vo, cloth, 4*s.* 6*d.*

Laying and Repairing Electric Telegraph Cables. By Capt. V. HOSKIŒR, Royal Danish Engineers. Crown 8vo, cloth, 3*s.* 6*d.*

A Pocket-Book of Practical Rules for the Proportions of Modern Engines and Boilers for Land and Marine purposes. By N. P. BURGH. Seventh edition, royal 32mo, roan, 4*s.* 6*d.*

The Assayer's Manual: an Abridged Treatise on the Docimastic Examination of Ores and Furnace and other Artificial Products. By BRUNO KERL. Translated by W. T. BRANNT. *With* 65 *illustrations*, 8vo, cloth, 12*s.* 6*d.*

The Steam Engine considered as a Heat Engine: a Treatise on the Theory of the Steam Engine, illustrated by Diagrams, Tables, and Examples from Practice. By JAS. H. COTTERILL, M.A., F.R.S., Professor of Applied Mechanics in the Royal Naval College. 8vo, cloth, 12*s.* 6*d.*

Electricity: its Theory, Sources, and Applications. By J. T. SPRAGUE, M.S.T.E. Second edition, revised and enlarged, with *numerous illustrations*, crown 8vo, cloth, 15*s*.

The Practice of Hand Turning in Wood, Ivory, Shell, etc., with Instructions for Turning such Work in Metal as may be required in the Practice of Turning in Wood, Ivory, etc.; also an Appendix on Ornamental Turning. (A book for beginners.) By FRANCIS CAMPIN. Third edition, *with wood engravings*, crown 8vo, cloth, 6*s*.

CONTENTS:

On Lathes—Turning Tools—Turning Wood—Drilling—Screw Cutting—Miscellaneous Apparatus and Processes—Turning Particular Forms—Staining—Polishing—Spinning Metals—Materials—Ornamental Turning, etc.

Health and Comfort in House Building, or Ventilation with Warm Air by Self-Acting Suction Power, with Review of the mode of Calculating the Draught in Hot-Air Flues, and with some actual Experiments. By J. DRYSDALE, M.D., and J. W. HAYWARD, M.D. Second edition, with Supplement, *with plates*, demy 8vo, cloth, 7*s*. 6*d*.

Treatise on Watchwork, Past and Present. By the Rev. H. L. NELTHROPP, M.A., F.S.A. *With* 32 *illustrations*, crown 8vo, cloth, 6*s*. 6*d*.

CONTENTS:

Definitions of Words and Terms used in Watchwork—Tools—Time—Historical Summary—On Calculations of the Numbers for Wheels and Pinions; their Proportional Sizes, Trains, etc.—Of Dial Wheels, or Motion Work—Length of Time of Going without Winding up—The Verge—The Horizontal—The Duplex—The Lever—The Chronometer—Repeating Watches—Keyless Watches—The Pendulum, or Spiral Spring—Compensation—Jewelling of Pivot Holes—Clerkenwell—Fallacies of the Trade—Incapacity of Workmen—How to Choose and Use a Watch, etc.

Notes in Mechanical Engineering. Compiled principally for the use of the Students attending the Classes on this subject at the City of London College. By HENRY ADAMS, Mem. Inst. M.E., Mem. Inst. C.E., Mem. Soc. of Engineers. Crown 8vo, cloth, 2*s*. 6*d*.

Algebra Self-Taught. By W. P. HIGGS, M.A., D.Sc., LL.D., Assoc. Inst. C.E., Author of 'A Handbook of the Differential Calculus,' etc. Second edition, crown 8vo, cloth, 2*s*. 6*d*.

CONTENTS:

Symbols and the Signs of Operation—The Equation and the Unknown Quantity—Positive and Negative Quantities—Multiplication—Involution—Exponents—Negative Exponents—Roots, and the Use of Exponents as Logarithms—Logarithms—Tables of Logarithms and Proportionate Parts—Transformation of System of Logarithms—Common Uses of Common Logarithms—Compound Multiplication and the Binomial Theorem—Division, Fractions, and Ratio—Continued Proportion—The Series and the Summation of the Series—Limit of Series—Square and Cube Roots—Equations—List of Formulæ, etc.

Spons' Dictionary of Engineering, Civil, Mechanical, Military, and Naval; with technical terms in French, German, Italian, and Spanish, 3100 pp., and *nearly* 8000 *engravings*, in super-royal 8vo, in 8 divisions, 5*l*. 8*s*. Complete in 3 vols., cloth, 5*l*. 5*s*. Bound in a superior manner, half-morocco, top edge gilt, 3 vols., 6*l*. 12*s*.

In super-royal 8vo, 1168 pp., *with 2400 illustrations*, in 3 Divisions, cloth, price 13*s*. 6*d*. each; or 1 vol., cloth, 2*l*.; or half-morocco, 2*l*. 8*s*.

A SUPPLEMENT

TO

SPONS' DICTIONARY OF ENGINEERING.

EDITED BY ERNEST SPON, MEMB. SOC. ENGINEERS.

Abacus, Counters, Speed Indicators, and Slide Rule.
Agricultural Implements and Machinery.
Air Compressors.
Animal Charcoal Machinery.
Antimony.
Axles and Axle-boxes.
Barn Machinery.
Belts and Belting.
Blasting. Boilers.
Brakes.
Brick Machinery.
Bridges.
Cages for Mines.
Calculus, Differential and Integral.
Canals.
Carpentry.
Cast Iron.
Cement, Concrete, Limes, and Mortar.
Chimney Shafts.
Coal Cleansing and Washing.
Coal Mining.
Coal Cutting Machines.
Coke Ovens. Copper.
Docks. Drainage.
Dredging Machinery.
Dynamo - Electric and Magneto-Electric Machines.
Dynamometers.
Electrical Engineering, Telegraphy, Electric Lighting and its practicaldetails, Telephones
Engines, Varieties of.
Explosives. Fans.
Founding, Moulding and the practical work of the Foundry.
Gas, Manufacture of.
Hammers, Steam and other Power.
Heat. Horse Power.
Hydraulics.
Hydro-geology.
Indicators. Iron.
Lifts, Hoists, and Elevators.
Lighthouses, Buoys, and Beacons.
Machine Tools.
Materials of Construction.
Meters.
Ores, Machinery and Processes employed to Dress.
Piers.
Pile Driving.
Pneumatic Transmission.
Pumps.
Pyrometers.
Road Locomotives.
Rock Drills.
Rolling Stock.
Sanitary Engineering.
Shafting.
Steel.
Steam Navvy.
Stone Machinery.
Tramways.
Well Sinking.

London: E. & F. N. SPON, 125, Strand.
New York: 35, Murray Street.

NOW COMPLETE.

With nearly 1500 *illustrations*, in super-royal 8vo, in 5 Divisions, cloth Divisions 1 to 4, 13*s*. 6*d*. each ; Division 5, 17*s*. 6*d*. ; or 2 vols., cloth, £3 10s.

SPONS' ENCYCLOPÆDIA

OF THE

INDUSTRIAL ARTS, MANUFACTURES, AND COMMERCIAL PRODUCTS.

EDITED BY C. G. WARNFORD LOCK, F.L.S.

Among the more important of the subjects treated of, are the following :—

- Acids, 207 pp. 220 figs.
- Alcohol, 23 pp. 16 figs.
- Alcoholic Liquors, 13 pp.
- Alkalies, 89 pp. 78 figs.
- Alloys.
- Alum.
- Asphalt.
- Assaying.
- Beverages, 89 pp. 29 figs.
- Blacks.
- Bleaching Powder, 15 pp.
- Bleaching, 51 pp. 48 figs.
- Candles, 18 pp. 9 figs.
- Carbon Bisulphide.
- Celluloid, 9 pp.
- Cements.
- Clay.
- Coal-tar Products, 44 pp. 14 figs.
- Cocoa, 8 pp.
- Coffee, 32 pp. 13 figs.
- Cork, 8 pp. 17 figs.
- Cotton Manufactures, 62 pp. 57 figs.
- Drugs, 38 pp.
- Dyeing and Calico Printing, 28 pp. 9 figs.
- Dyestuffs, 16 pp.
- Electro-Metallurgy, 13 pp.
- Explosives, 22 pp. 33 figs.
- Feathers.
- Fibrous Substances, 92 pp. 79 figs.
- Floor-cloth, 16 pp. 21 figs.
- Food Preservation, 8 pp.
- Fruit, 8 pp.
- Fur, 5 pp.
- Gas, Coal, 8 pp.
- Gems.
- Glass, 45 pp. 77 figs.
- Graphite, 7 pp.
- Hair, 7 pp.
- Hair Manufactures.
- Hats, 26 pp. 26 figs.
- Honey.
- Hops.
- Horn.
- Ice, 10 pp. 14 figs.
- Indiarubber Manufactures, 23 pp. 17 figs.
- Ink, 17 pp.
- Ivory.
- Jute Manufactures, 11 pp., 11 figs.
- Knitted Fabrics — Hosiery, 15 pp. 13 figs.
- Lace, 13 pp. 9 figs.
- Leather, 28 pp. 31 figs.
- Linen Manufactures, 16 pp. 6 figs.
- Manures, 21 pp. 30 figs.
- Matches, 17 pp. 38 figs.
- Mordants, 13 pp.
- Narcotics, 47 pp.
- Nuts, 10 pp.
- Oils and Fatty Substances, 125 pp.
- Paint.
- Paper, 26 pp. 23 figs.
- Paraffin, 8 pp. 6 figs.
- Pearl and Coral, 8 pp.
- Perfumes, 10 pp.
- Photography, 13 pp. 20 figs.
- Pigments, 9 pp. 6 figs.
- Pottery, 46 pp. 57 figs.
- Printing and Engraving, 20 pp. 8 figs.
- Rags.
- Resinous and Gummy Substances, 75 pp. 16 figs.
- Rope, 16 pp. 17 figs.
- Salt, 31 pp. 23 figs.
- Silk, 8 pp.
- Silk Manufactures, 9 pp. 11 figs.
- Skins, 5 pp.
- Small Wares, 4 pp.
- Soap and Glycerine, 39 pp. 45 figs.
- Spices, 16 pp.
- Sponge, 5 pp.
- Starch, 9 pp. 10 figs.
- Sugar, 155 pp. 134 figs.
- Sulphur.
- Tannin, 18 pp.
- Tea, 12 pp.
- Timber, 13 pp.
- Varnish, 15 pp.
- Vinegar, 5 pp.
- Wax, 5 pp.
- Wool, 2 pp.
- Woollen Manufactures, 58 pp. 39 figs.

London: E. & F. N. SPON, 125, Strand.
New York: 35, Murray Street.

Crown 8vo, cloth, with illustrations, 5*s*.

WORKSHOP RECEIPTS,

FIRST SERIES.

BY ERNEST SPON.

SYNOPSIS OF CONTENTS.

Bookbinding.
Bronzes and Bronzing.
Candles.
Cement.
Cleaning.
Colourwashing.
Concretes.
Dipping Acids.
Drawing Office Details.
Drying Oils.
Dynamite.
Electro - Metallurgy — (Cleaning, Dipping, Scratch-brushing, Batteries, Baths, and Deposits of every description).
Enamels.
Engraving on Wood, Copper, Gold, Silver, Steel, and Stone.
Etching and Aqua Tint.
Firework Making — (Rockets, Stars, Rains, Gerbes, Jets, Tourbillons, Candles, Fires, Lances, Lights, Wheels, Fire-balloons, and minor Fireworks).
Fluxes.
Foundry Mixtures.
Freezing.
Fulminates.
Furniture Creams, Oils, Polishes, Lacquers, and Pastes.
Gilding.
Glass Cutting, Cleaning, Frosting, Drilling, Darkening, Bending, Staining, and Painting.
Glass Making.
Glues.
Gold.
Graining.
Gums.
Gun Cotton.
Gunpowder.
Horn Working.
Indiarubber.
Japans, Japanning, and kindred processes.
Lacquers.
Lathing.
Lubricants.
Marble Working.
Matches.
Mortars.
Nitro-Glycerine.
Oils.
Paper.
Paper Hanging.
Painting in Oils, in Water Colours, as well as Fresco, House, Transparency, Sign, and Carriage Painting.
Photography.
Plastering.
Polishes.
Pottery—(Clays, Bodies, Glazes, Colours, Oils, Stains, Fluxes, Enamels, and Lustres).
Scouring.
Silvering.
Soap.
Solders.
Tanning.
Taxidermy.
Tempering Metals.
Treating Horn, Mother-o'-Pearl, and like substances.
Varnishes, Manufacture and Use of.
Veneering.
Washing.
Waterprofing.
Welding.

Besides Receipts relating to the lesser Technological matters and processes, such as the manufacture and use of Stencil Plates, Blacking, Crayons, Paste, Putty, Wax, Size, Alloys, Catgut, Tunbridge Ware, Picture Frame and Architectural Mouldings, Compos, Cameos, and others too numerous to mention.

London: E. & F. N. SPON, 125, Strand.
New York: 35, Murray Street.

Crown 8vo, cloth, 485 pages, with illustrations, 5*s.*

WORKSHOP RECEIPTS.

SECOND SERIES.

BY ROBERT HALDANE.

SYNOPSIS OF CONTENTS.

- Acidimetry and Alkalimetry.
- Albumen.
- Alcohol.
- Alkaloids.
- Baking-powders.
- Bitters.
- Bleaching.
- Boiler Incrustations.
- Cements and Lutes.
- Cleansing.
- Confectionery.
- Copying.
- Disinfectants.
- Dyeing, Staining, and Colouring.
- Essences.
- Extracts.
- Fireproofing.
- Gelatine, Glue, and Size.
- Glycerine.
- Gut.
- Hydrogen peroxide.
- Ink.
- Iodine.
- Iodoform.
- Isinglass.
- Ivory substitutes.
- Leather.
- Luminous bodies.
- Magnesia.
- Matches.
- Paper.
- Parchment.
- Perchloric acid.
- Potassium oxalate.
- Preserving.

Pigments, Paint, and Painting: embracing the preparation of *Pigments*, including alumina lakes, blacks (animal, bone, Frankfort, ivory, lamp, sight, soot), blues (antimony, Antwerp, cobalt, cœruleum, Egyptian, manganate, Paris, Péligot, Prussian, smalt, ultramarine), browns (bistre, hinau, sepia, sienna, umber, Vandyke), greens (baryta, Brighton, Brunswick, chrome, cobalt, Douglas, emerald, manganese, mitis, mountain, Prussian, sap, Scheele's, Schweinfurth, titanium, verdigris, zinc), reds (Brazilwood lake, carminated lake, carmine, Cassius purple, cobalt pink, cochineal lake, colcothar, Indian red, madder lake, red chalk, red lead, vermilion), whites (alum, baryta, Chinese, lead sulphate, white lead—by American, Dutch, French, German, Kremnitz, and Pattinson processes, precautions in making, and composition of commercial samples—whiting, Wilkinson's white, zinc white), yellows (chrome, gamboge, Naples, orpiment, realgar, yellow lakes); *Paint* (vehicles, testing oils, driers, grinding, storing, applying, priming, drying, filling, coats, brushes, surface, water-colours, removing smell, discoloration; miscellaneous paints—cement paint for carton-pierre, copper paint, gold paint, iron paint, lime paints, silicated paints, steatite paint, transparent paints, tungsten paints, window paint, zinc paints); *Painting* (general instructions, proportions of ingredients, measuring paint work; carriage painting—priming paint, best putty, finishing colour, cause of cracking, mixing the paints, oils, driers, and colours, varnishing, importance of washing vehicles, re-varnishing, how to dry paint; woodwork painting).

London: E. & F. N. SPON, 125, Strand.
New York: 35, Murray Street.

JUST PUBLISHED.

Crown 8vo, cloth, 480 pages, with 183 illustrations, 5*s*.

WORKSHOP RECEIPTS,

THIRD SERIES.

BY C. G. WARNFORD LOCK.

Uniform with the First and Second Series.

SYNOPSIS OF CONTENTS.

Alloys.
Aluminium.
Antimony.
Barium.
Beryllium.
Bismuth.
Cadmium.
Cæsium.
Calcium.
Cerium.
Chromium.
Cobalt.
Copper.
Didymium.
Electrics.
Enamels and Glazes.
Erbium.
Gallium.
Glass.
Gold.
Indium.
Iridium.
Iron and Steel.
Lacquers and Lacquering.
Lanthanum.
Lead.
Lithium.
Lubricants.
Magnesium.
Manganese.
Mercury.
Mica.
Molybdenum.
Nickel.
Niobium.
Osmium.
Palladium.
Platinum.
Potassium.
Rhodium.
Rubidium.
Ruthenium.
Selenium.
Silver.
Slag.
Sodium.
Strontium.
Tantalum.
Terbium.
Thallium.
Thorium.
Tin.
Titanium.
Tungsten.
Uranium.
Vanadium.
Yttrium.
Zinc.
Zirconium.
Aluminium.

London: E. & F. N. SPON, 125, Strand.
New York: 35, Murray Street.

JUST PUBLISHED.

In demy 8vo, cloth, 600 pages, and 1420 Illustrations, *6s.*

SPONS'

MECHANIC'S OWN BOOK;

A MANUAL FOR HANDICRAFTSMEN AND AMATEURS.

CONTENTS.

Mechanical Drawing—Casting and Founding in Iron, Brass, Bronze, and other Alloys—Forging and Finishing Iron—Sheetmetal Working—Soldering, Brazing, and Burning—Carpentry and Joinery, embracing descriptions of some 400 Woods, over 200 Illustrations of Tools and their uses, Explanations (with Diagrams) of 116 joints and hinges, and Details of Construction of Workshop appliances, rough furniture, Garden and Yard Erections, and House Building—Cabinet-Making and Veneering—Carving and Fretcutting—Upholstery—Painting, Graining, and Marbling—Staining Furniture, Woods, Floors, and Fittings—Gilding, dead and bright, on various grounds—Polishing Marble, Metals, and Wood—Varnishing—Mechanical movements, illustrating contrivances for transmitting motion—Turning in Wood and Metals—Masonry, embracing Stonework, Brickwork, Terracotta, and Concrete—Roofing with Thatch, Tiles, Slates, Felt, Zinc, &c.—Glazing with and without putty, and lead glazing—Plastering and Whitewashing—Paper-hanging—Gas-fitting—Bell-hanging, ordinary and electric Systems—Lighting—Warming—Ventilating—Roads, Pavements, and Bridges—Hedges, Ditches, and Drains—Water Supply and Sanitation—Hints on House Construction suited to new countries.

London: E. & F. N. SPON, 125, Strand.
New York: 35, Murray Street.

47

89089683965

b89089683965a